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Dwarf Mistletoe Impact Modeling System

User Guide and Reference Manual Nonspatial Model

2005 Update

USDA Forest Service
Forest Health Technology Enterprise Team

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Impact Modeling System

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Reference Manual
Nonspatial Model

2005 Update

by

Lance R. David (FHTET / ITX contract)

The spatial version of the Dwarf Mistletoe Model is not supported by USDA Forest Service Forest Heath Technology Enterprise Team; therefore, information relevant only to the spatial model has been removed from this document.

Original document written by

Frank G. Hawksworth, Julie C. Williams-Cipriani, Bov B. Eav,
Brian W. Geils, Ralph R. Johnson, Michael A. Marsden,
Jerome S. Beatty, Gregory D. Shubert, and Donald C.E. Robinson

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Forest Health Technology Enterprise Team
Fort Collins, CO

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1.1 Understanding the Threat of Dwarf Mistletoe on Coniferous Forests in the Western United States

Dwarf mistletoe species have substantial deleterious impacts on the growth and mortality of trees and stands in the Western United States.

The dwarf mistletoes (*Arceuthobium* spp.) are some of the most widespread and serious forest disease-causing agents of western conifers. They adversely affect the growth, survival, and reproductive potential of a number of important tree species in western North America. The estimated loss of more than 400 million cubic feet of timber per year due to dwarf mistletoe infection (Drummond 1982) is probably conservative, and since volume losses are reported for commercial forest lands only, this figure does not take into account the effects on forest stands used for recreation, wildlife, watershed, and visual quality. Another source estimates the timber product losses due to dwarf mistletoe at 3.3 billion board feet annually. Fifty percent of lodgepole pine and Douglas-fir forests and 35% of ponderosa pine forests in the central and southern Rockies are affected by dwarf mistletoe (Hawksworth and Scharpf 1984). On the following page, Exhibit 1.1 summarizes annual timber loss estimates due to growth reduction and tree mortality caused by dwarf mistletoe for various forest regions of the United States (Drummond 1982; unpublished data, Paul Hennon).

Region	**Area of All Species of Commercial Host Type** ***(millions of acres)***	**Infected Area** ***(millions of acres)***	**Total Annual Loss of Merchantable Timber** ***(millions of ft^3)***
Montana and Northern Idaho	12.9	3.4	47
Colorado and Eastern Wyoming	2.5	1.2	18
Arizona and New Mexico	7.6	2.8	25
California	13.6	2.8	122
Oregon and Washington	36.1	8.5	148
Alaska	5.8	3.4	11
Michigan, Minnesota and Wisconsin	2.1	0.3	11
Southern Idaho, Utah, Nevada and Western Wyoming	6.5	2.6	36
Total	**87.1**	**25**	**418**

Exhibit 1.1 Estimates of Annual Timber Losses Attributed to Dwarf Mistletoe.

1.2 Using the Dwarf Mistletoe Impact Modeling System (DMIM): Practical Needs, Benefits, and Applications

Because of the tremendous losses encountered in forests of the Western United States due to dwarf mistletoe infections, the need for a more comprehensive mistletoe model for pest management, silvicultural planning, and timber and forest management is extremely important.

Since these damaging agents can often be controlled by silvicultural means (Hawksworth *et al.* 1987), growth and yield models that predict dwarf mistletoe impact have been of considerable interest to forest managers as they can be used for planning cultural operations and for estimating yields in specific stands. However, the programs available up to now were limited to certain forest types and conditions in the Southwest and Central Rocky Mountains, so they were not generally applicable to most affected areas in the West.

The first growth and yield model that included the effects of dwarf mistletoe (which was also the first for any forest pest) was for lodgepole pine dwarf mistletoe in the Central Rocky Mountains (Myers *et al.* 1971; Edminster 1987a). This was a whole-stand model that was applicable only to managed, even-aged stands. A similar model was developed for even-aged southwestern ponderosa pine (Myers *et al.* 1972), which was later expanded to include two-storied stands (Myers *et al*. 1976). These programs were later combined into the more generalized model (RMYLD) to provide for more flexible management options and a wider range of stand conditions (Edminster 1987b). These programs, plus an additional submodel for southwestern mixed conifer stands which includes the effects of dwarf mistletoes on Douglas-fir, Engelmann spruce, and blue spruce, were then updated and incorporated into the broader growth and yield model, GENGYM (Edminster *et al*. 1991). GENGYM simulates stands from single-species, single-story to multi-species and age groups.

Other growth and yield stand models that have been developed for dwarf mistletoe-infected stands are for western hemlock in southern British Columbia (Bloomberg *et al*. 1980; Bloomberg and Smith 1982; Muir 1986), ponderosa pine in the Pacific Northwest (DeMars and Barrett 1987), black spruce in the Lake States (Baker *et al*. 1982), and ponderosa pine in the Southwest (Larsen 1975). In addition, a number of other studies on various aspects of dwarf mistletoe epidemiology, spread, and damage have been published, but these have not yet been incorporated into formal growth and yield models:

- spread of dwarf mistletoe in southwestern ponderosa pine (Dixon and Hawksworth 1979);
- epidemiology of dwarf mistletoe in even-aged ponderosa pine in the Pacific Northwest (Strand and Roth 1976); and
- epidemiology and effects of dwarf mistletoe in uneven-aged ponderosa pine stands in Colorado (Maffei 1989).

Meanwhile, the Forest Vegetation Simulator (FVS) growth and yield program, based on individual tree-diameter distributions, was being developed for stands in the northern Rocky Mountains (Wykoff *et al.* 1982). Later it was expanded to other areas in the Pacific Northwest, the Intermountain region, and California. The original FVS program did not include the effects of dwarf mistletoes. However, because of the widespread occurrence of these parasites in the coniferous forests of the West, forest managers soon saw the need for incorporating their effects in growth and yield projections. The first attempt to include dwarf mistletoe effects in an FVS model was in SORNEC, a variant developed for southern Oregon and northeastern California (Johnson *et al*. 1986). Since this preliminary model considered only the effects of dwarf mistletoe on diameter growth (other effects of dwarf mistletoe such as tree mortality

were not modeled), it underestimated the effects of these disease agents. Thus, it was decided at a modeling workshop in 1990 (McNamee *et al*. 1990) that further investigation and analyses were needed to incorporate more dwarf mistletoe effects into the FVS variants that include coastal and southwestern ponderosa pine, lodgepole pine, Douglas-fir, western larch, true firs, and western hemlock. As an interim step until all the research and analyses could be performed to complete the task, it was also suggested that a preliminary model, based on analyses of all existing data and “best guesses,” be prepared. With this information in mind, the Dwarf Mistletoe Impact Modeling (DMIM) System was written to run in conjunction with the FVS model for 17 of the FVS variants.

1.3 How to Use this Dwarf Mistletoe Model User’s Guide and Reference Manual

This user’s guide and reference manual is written in modular format and is comprised of three chapters: 1) *Introduction*; 2) *Scientific Background*; and 3) *Using the Model*

The Dwarf Mistletoe Impact Modeling (DMIM) System User’s Guide and Reference Manual is written in a modular format. Each module is two to four pages long and addresses a specific DMIM system function or issue. Each contains a headline, a summary statement about the module, the module content, and usually one or more exhibits, such as a table or graph.

The first chapter, *Introduction*, provides pest information and discusses the need for the DMIM system. The second chapter, *Scientific Background*, deals with the development of the model and provides detailed explanations for each of the main modules of the DMIM system:

- spread and intensification using the nonspatial equations;
- diameter growth modification; and
- mortality.

The final chapter, *Using the Model*, gives instructions on how to access and manipulate the dwarf mistletoe model.

The appendices include a list of tree species abbreviations, a list of common abbreviations used in this document, and a list of species affected by mistletoe by variant. The tree species list includes tree species abbreviations, common names, and scientific names. The second list of abbreviations is comprised of those words and phrases in this document (other than tree species) that are commonly abbreviated. The reference list that follows the appendices includes sources specifically referred to in the text and sources used by the authors for more general information. Those sources referred to within the manual are noted by a reference (e.g. Hawksworth and Geils 1990).

Prior to using the DMIM system, the user should:

- have a general knowledge of dwarf mistletoe;
- know how to run Forest Vegetation Simulator (FVS); and
- have access to the *User’s Guide to the Stand Prognosis Model* (Wykoff *et al*. 1982).

Chapter 2 - Biological Background

2.1 How Dwarf Mistletoe Modeling Data Was Adapted from Various Sources

2.2 Understanding the Main Modules of the Dwarf Mistletoe Impact Model

2.3 Spread and Intensification of Dwarf Mistletoe Through a Stand

2.3.1 Nonspatial

2.4 How Diameter Growth Is Modified

2.4.1 The Lodgepole Pine Growth Modification Equation
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2.1 How Dwarf Mistletoe Modeling Data was Adapted from Various Sources

Dwarf mistletoe impact data were collected from numerous publications and personal communications involving a variety of geographical locations, for different tree species and stand types.

Data for the DMIM system were collected from studies conducted all over the Western United States, as well as from personal communications with Forest Service personnel from many regions. Data were taken from forests in Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Washington, and Wyoming. The model focuses on the following species: lodgepole pine, ponderosa pine, Douglas-fir, true firs, western larch, and western hemlock.

These species were selected for various reasons: their susceptibility to dwarf mistletoe infection, their importance in stands in the Western United States, their availability in FVS, and the availability of dwarf mistletoe infection study data on these species. The model was, therefore, limited by the amount and type of data available. Other species that are similarly affected by dwarf mistletoe infections are included wherever possible and are represented by one of the species listed above.

The DMIM is based on directly measurable attributes in order to make it available for use in a timely manner. The model dynamics are based on Hawksworth’s six-class dwarf mistletoe rating (DMR) system (Hawksworth 1977). Besides species, DBH, site index, stand density in trees per acre, and height growth also contribute to the projected changes in infection status.

The map in Exhibit 2.1 shows the range of locations from which data (both published and unpublished) was obtained for the design and modeling of the Dwarf Mistletoe Impact Modeling (DMIM) system.

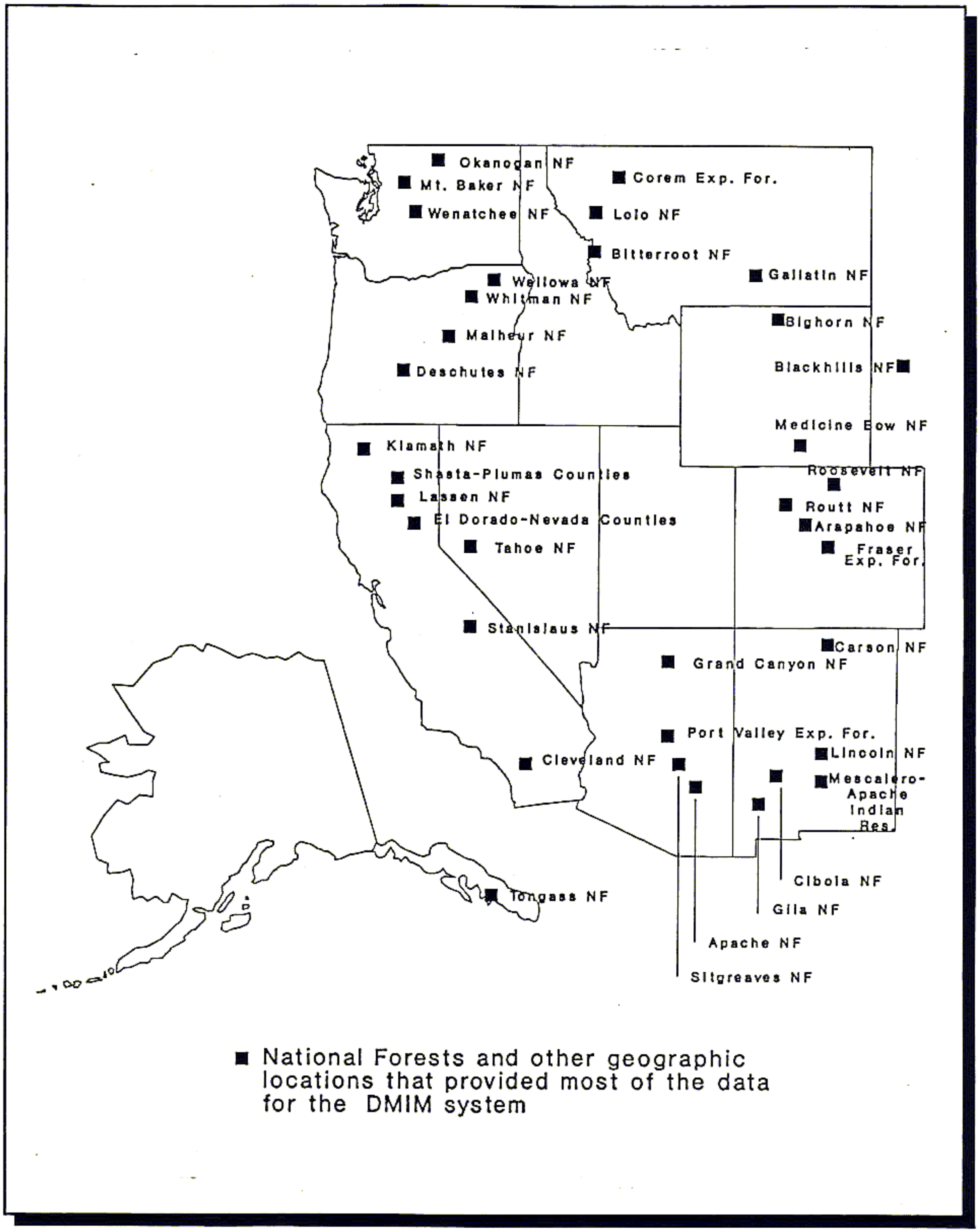

Exhibit 2.1 Data sources for the Dwarf Mistletoe Impact Model.

2.2 Understanding the Main Modules of the Dwarf Mistletoe Impact Model

The DMIM system is made up of four main modules: 1) and 2) predict the nonspatial spread and intensification; 3) predicts diameter growth modification; and 4) predicts mortality. Generally, each of these modules is also broken down by tree species and DMR class.

The model accounts for three indicators when projecting the impact of dwarf mistletoe on a tree or a stand. The first of these indicators is the change in an individual tree's DMR as mistletoe spreads through a stand. This measure also includes the intensification of dwarf mistletoe within trees that are already infected. The process for simulating spread and intensification is regression-based nonspatial equations. The likelihood that an individual tree will increase or decrease its dwarf mistletoe rating during the current cycle are dependent upon several factors. Besides tree species and current DMR, factors that affect the likelihood of increasing or decreasing DMR are the estimates of DBH, stand density, height-growth and the presence of infected overstory.

In order to recognize spatial influence in a most simplistic, yet still meaningful method, sample points are utilized if present in the input data and trees on individual points are processed with relevance to other trees on the same point. The most influential characteristic that may be utilized for each point is its tallest dwarf mistletoe infected tree which may serve as a overstory source of infection for smaller trees of the same specie on the point. A tree that is 70% or less the height of the tallest infected tree of the same species on the point is considered influenced by an overstory source and therefore is subject to elevated potential for infection. Uninfected trees that become infected contribute to spread of the disease and infected trees that acquire additional infections is categorized as intensification.

The model's second indicator is the change in periodic diameter growth caused by dwarf mistletoe infestation. This projection is based on the species and current DMR. For some species, low levels of dwarf mistletoe infection have no adverse effects on diameter growth. Trees of some other species may experience growth loss with even the lowest levels of mistletoe infection.

The model's third indicator is the mortality caused by dwarf mistletoe infestation. Predicted mortality depends on species, DMR, DBH, and site index. As with other pest extensions to the FVS models, reconciliation is made between the mortality predicted to occur because of dwarf mistletoe, and the mortality predicted by the base FVS model (including suppression and all other causes). Comparing the two predictions on an individual tree basis each cycle, the larger of the two mortality predictions is used.

Each cycle, these modules are called from FVS in a certain order, consistent with the sequence in which the base (non-mistletoe) FVS model projections are made. For example, mistletoe diameter growth modifications are computed and put into effect before dwarf mistletoe ratings have been updated for that cycle (in the spread and intensification module). The diagram in Exhibit 2.2 shows the sequence in which the mistletoe modules are called in relation to other FVS activities, including when mistletoe statistical output tables are produced for each cycle.

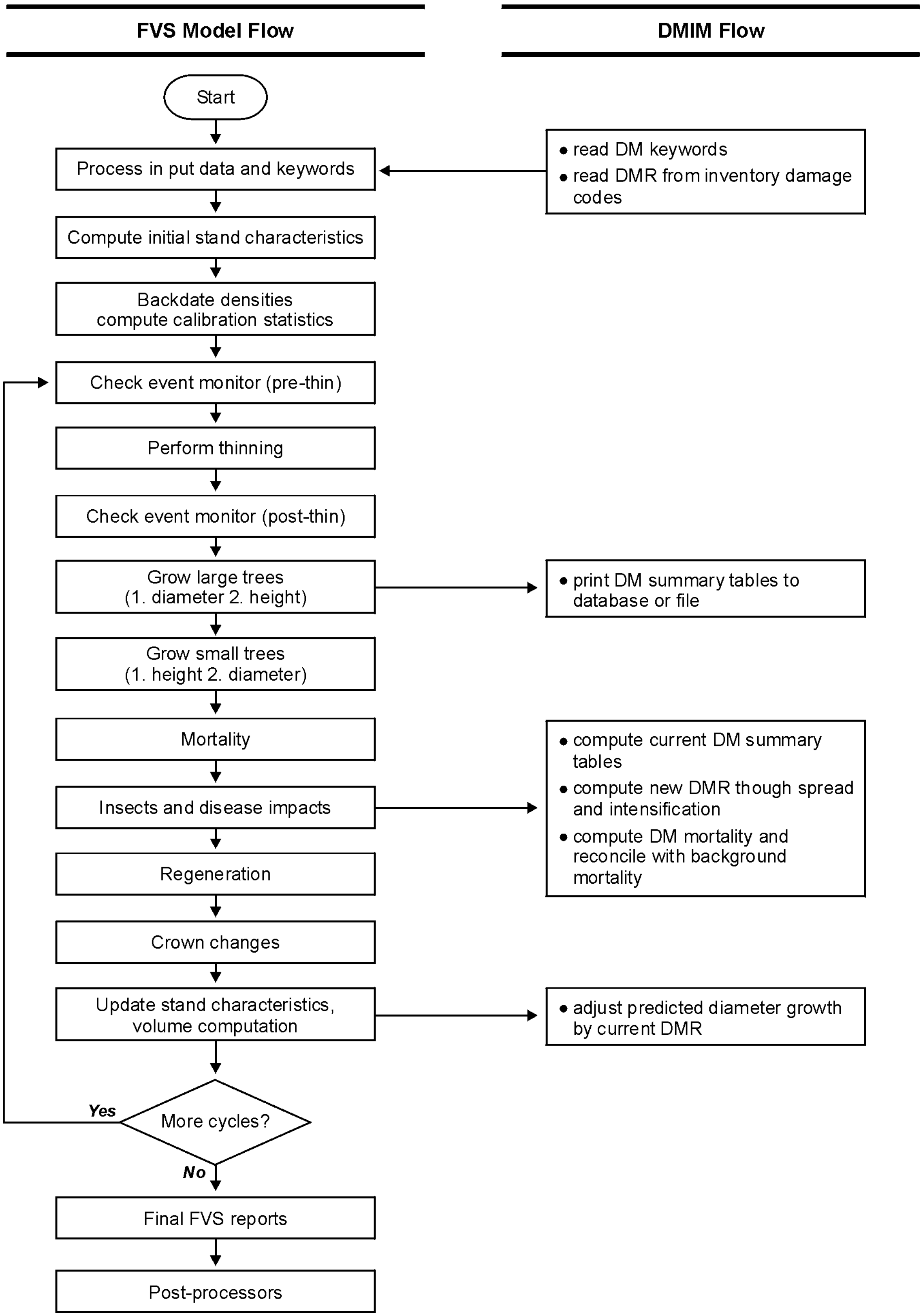

Exhibit 2.2 Sequence of events within FVS, including DMIM model calls.

2.3 Spread and Intensification of Dwarf Mistletoe Through a Stand

Two equations determine spread and intensification of dwarf mistletoe through each tree in a stand: one equation for the probability of an increase in DMR and one for the probability of a decrease in DMR.

If a tree record is listed as dwarf mistletoe-infected, there needs to be an equation-based mechanism for passing this infection on to other trees in the stand, as well as for increasing or decreasing the level of infection on already-infected tree records. This mechanism is what is known as the spread and intensification module of the `DMIM` system. It is based on a study of 1,200 lodgepole pine in Gallatin National Forest in Montana (Dooling et al. 1986). (Intensification data are available from other studies and may be used in a more comprehensive model, but this model uses equations from Region 1.) Using the data collected from this study, a logistic regression was fitted to estimate the probability of a tree changing from one dwarf mistletoe rating to the next (Ralph Johnson, unpublished data). The probability of change is calculated separately for increases in DMR (a tree in which more of the crown becomes infected) and decreases in DMR (a tree growing out of its mistletoe infection). Once these probabilities are calculated for a tree in the current cycle, they are compared to a number that is drawn at random from a uniform distribution with a range of 0 to 1. If the probability of increase is larger than the random number, then the tree DMR is increased by one or more. If the probability of decrease is larger than another separately drawn random number, then the tree DMR is decreased by one

When a tree has been selected for intensification, an additional process is performed if the tree is influenced by overstory infections. In the case of infected overstory, the increase in DMR is not limited to one, but may be increased by two or even three. The increase of DMR by more than one is determined by a drawn random number and the tree’s current DMR. Naturally, a tree with a DMR of five is only eligible for an increase of one and not two or three. The distribution of DMR increases for trees under infected overstory are dependant upon the tree’s current DMR as listed below and remember that this distribution is dependent first on the tree being selected for an increase.

Current DMR	Increase of 1	Increase of 2	Increase of 3
1	61%	17%	22%
2	33%	33%	34%
3	33%	33%	34%
4	54%	46%	
5	100%		

When the drawn random number is less than the calculated probability of increase and the tree is currently uninfected, the DMR is set to one if there is no overstory infection source. If overstory infection is a factor, the tree is considered to have a 55% chance of becoming infected and within that 55%, the initial DMR is set to one 69% of the time, set to two 18% of the time and set to three the remaining 13%.

See Appendix C for a list of tree species by FVS variant which are affected in the model by spread and intensification of dwarf mistletoe through a stand in the model.

Probability of an increase in DMR for any species that is affected by dwarf mistletoe in a given variant is calculated from a logistic regression as follows:

$$P_I = \frac{1}{1+e^{-(-1.67226+MD-0.074720HG-0.0012397TPA)}} \times UIM$$

Similarly, the probability of a decrease in DMR for any species that is affected by dwarf mistletoe in a given variant is calculated as follows:

$$P_D = \frac{1}{1+e^{-(-5.59798+0.013267HG-0.00011505TPA+0.098376DMR)}} \times UIM$$

where:

P_I	=	probability that the rating will increase
P_D	=	probability that the rating will decrease by 1
DMR	=	current dwarf mistletoe rating
HG	=	height growth of the tree (feet per cycle)
TPA	=	density of the stand (trees per acre)
UIM	=	user input multiplier supplied using the MISTMULT keyword
MD	=	mistletoe "dummy" variables with the following values:

DMR	**Coefficient**
0	0.0
1	2.45047
2	2.30723
3	1.88090
4	2.11457
5	1.43293
6	0.0

The model structure makes it impossible to increase the rating of a tree with a DMR of 6, nor is it possible to decrease the rating of a tree with a DMR of 0.

Special note on the intensification process:
The determination of DMR increase and DMR decrease is independent of one another and therefore it is possible that a tree's DMR increases by two and then decreases by one in the same cycle resulting in a net increase of one DMR.

2.4 How Diameter Growth is Modified

There are five different equations for diameter growth modification, one for each of the following species: lodgepole pine, western larch, Douglas-fir, true firs, and ponderosa pine. All other species whose growth is significantly affected by dwarf mistletoe are currently emulated by one of these five equations.

Diameter growth for an individual tree may be modified when a dwarf mistletoe infection is present. A healthy tree has a potential of 100% growth for a given cycle. The model then calculates the proportion of that growth that would be lost due to mistletoe, based on that tree's DMR, species, and DBH. In addition, factors such as the FVS variant and the cycle length can modify diameter growth. This predicted mistletoe growth loss is then translated into a proportion of potential growth, which is used as a multiplier against the estimated healthy growth. Normal (healthy) diameter growth (in inches) is estimated using a variety of factors such as basal area, current diameter, site index, crown competition, elevation, aspect, slope, and species. In turn, the calculated diameter growth plays a role in making other calculations such as estimated height growth. Therefore, any diameter growth lost due to mistletoe will automatically alter estimated height growth for a tree.

Mistletoe diameter growth modification proportions for the model are stored in table format based on DMR, species, and the FVS variant. These are average values taken from a number of published and unpublished sources across the western US. These DMR, species, and variant-specific values are used in equations which also take into account cycle length, site factors, and user input mistletoe diameter growth modification proportions (see the MISTGMOD keyword section of this manual). There are essentially five of these equations, one to model each of the following species: lodgepole pine, western larch, Douglas-fir, true firs, and ponderosa pine. Any other species native to a given area which is affected by mistletoe will be emulated by one of the five models listed above based on which species it is more closely related to in terms of how it is affected by mistletoe.

Only sample trees with a DMR of 1 or greater at the start of the cycle are considered to be infected. No change in tree growth is calculated by this model for sample trees that are not infected (DMR=0) at the start of the cycle.

See Appendix C for a list of tree species by FVS variant which are susceptible to diameter growth loss in the model due to dwarf mistletoe infection.

2.4.1 The Lodgepole Pine Growth Modification Equation

This section includes the data used to build the lodgepole pine mistletoe growth modification equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The lodgepole pine diameter growth modification equation is based on the percentages listed in the table in Exhibit 2.3, which shows how diameter growth potential corresponds to DMR:

DMR	**0**	**1**	**2**	**3**	**4**	**5**	**6**
10-year diameter growth potential (percent)	100	100	100	100	94	80	59

Exhibit 2.3 Relationship of lodgepole pine diameter growth potential to DMR.

Other species similarly affected by dwarf mistletoe which also use the lodgepole pine percentages are:

- sugar pine;
- white pine;
- white bark pine;
- limber pine; and
- western hemlock.

After diameter growth is calculated in FVS it is altered to account for dwarf mistletoe with the following equation:

$$ADG = NDG \times DGP \times \frac{CL}{10}$$

where:

ADG	=	altered diameter growth, in inches
NDG	=	normal diameter growth, in inches
DGP	=	dwarf mistletoe diameter growth potential based on DMR
CL	=	cycle length (converted from 10-year period to user input length)

The data used to formulate the relationship between DMR and diameter growth potential (Exhibit 2.3) are presented with sources in Exhibit 2.4 (all entries were translated from the original source into percent potential growth in 10 years and then averaged together for the model):

DMR	Region 6 Values (1) (%)	25 Even-aged Stands in CO(2) (%)	Open Stands in CO and WY(2) (%)	Dense Stands in CO and WY(2) (%)
0	100	100	100	100
1	100	100	100	100
2	100	100	100	100
3	100	100	100	100
4	94	94	95	93
5	80	80	82	78
6	59	59	56	61

Sources: A. H. Maffei and P. Hessburg, personal communication; Hawksworth and Hinds 1964.
B. Hawksworth and Johnson 1989.

Exhibit 2.4 Data and Sources for Exhibit 2.3

Exhibit 2.5 is a graph of the diameter growth modification equation for lodgepole pine with mistletoe infection (black points) and the data used to formulate the relationship between DMR and diameter growth (white points).

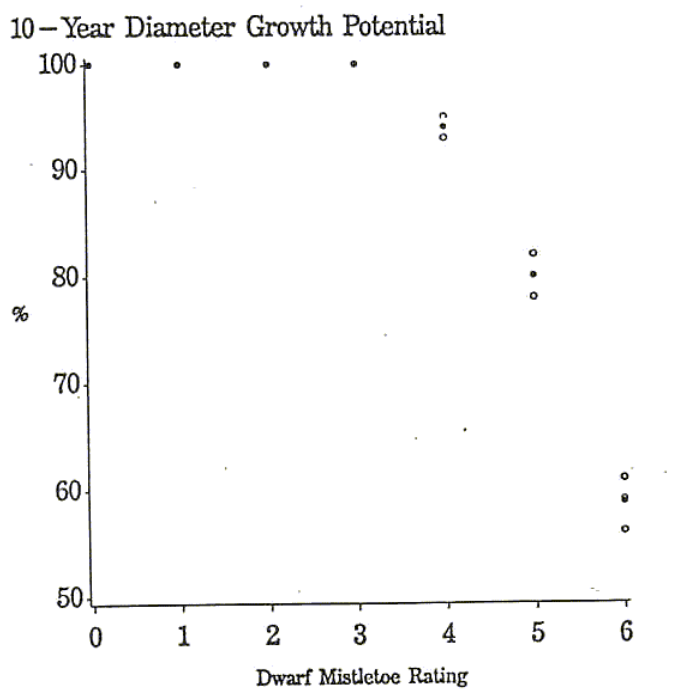

Exhibit 2.5 Lodgepole pine diameter growth potential vs. DMR.

2.4.2 The Western Larch Growth Modification Equation

This section includes the data used to build the western larch mistletoe growth modification equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The western larch growth modification equation is based on the percentages listed in the table in Exhibit 2.6, which shows how growth potential corresponds to DMR:

DMR	0	1	2	3	4	5	6
10-year diameter growth potential (percent)	100	94	92	88	84	58	54

Exhibit 2.6 Relationship of western larch diameter growth potential to DMR.

After diameter growth is calculated in FVS it is altered to account for dwarf mistletoe with the following equation:

$$ADG = NDG \times DGP \times \frac{CL}{10}$$

where:

ADG	=	altered diameter growth, in inches
NDG	=	normal diameter growth, in inches
DGP	=	dwarf mistletoe diameter growth potential based on DMR (taken from Exhibit 2.6 where percent is converted to a decimal or supplied using the MISTGMOD keyword)
CL	=	cycle length (converted from 10-year period to user input length)

The data used to formulate the relationship between DMR and diameter growth potential (Exhibit 2.6) are presented with sources in Exhibit 2.7 (all entries were translated from the original source into percent potential growth in 10 years and then averaged together for the model):

DMR	Region 6 Value (%)	70-year-old Stands in OR (%)	Thinned Stands (above) in OR (%)	Thinned Stands (below) in OR (%)
0	100	100	100	100
1	97	94	93	92
2	90	94	93	92
3	85	89	89	89
4	69	89	89	89
5	57	56	69	48
6	44	56	69	48

Source: Filip *et al.* 1989.

Exhibit 2.7 Data and Sources for Exhibit 2.6.

Exhibit 2.8 is a graph of the diameter growth modification equation for western larch with mistletoe infection (black points) and the data used to formulate the relationship between DMR and diameter growth (white points).

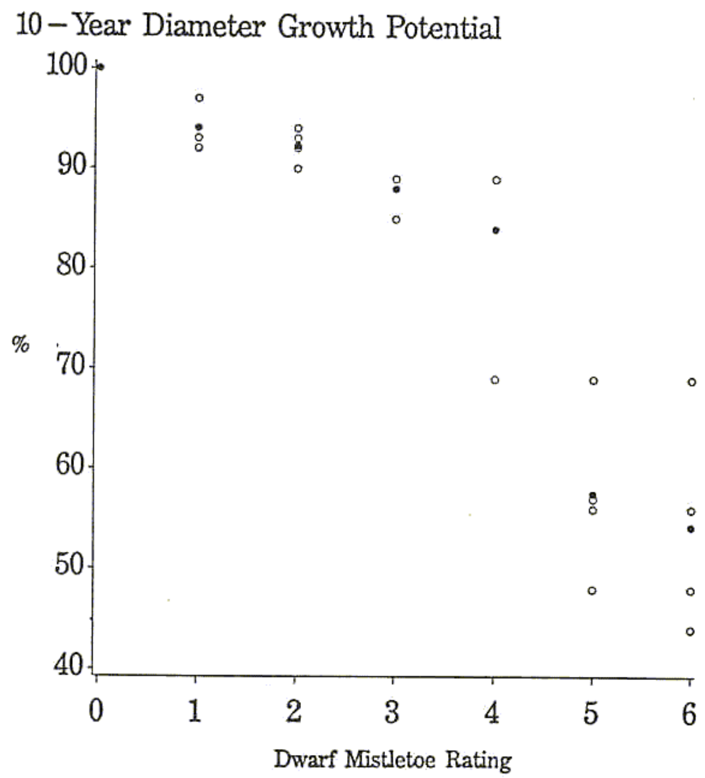

Exhibit 2.8 Western larch diameter growth potential vs. DMR.

2.4.3 The Douglas-fir Growth Modification Equation

This section includes the data used to build the Douglas-fir mistletoe growth modification equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The Douglas-fir diameter growth modification equation is based on the percentages listed in the table in Exhibit 2.9, which shows how growth potential corresponds to DMR:

DMR	0	1	2	3	4	5	6
10-year diameter growth potential (percent)	100	98	97	85	80	52	44

Exhibit 2.9 Relationship of Douglas-fir diameter growth potential to DMR.

Another species similarly affected by dwarf mistletoe which also uses the Douglas-fir percentages is:

- Engelmann spruce.

After diameter growth is calculated in FVS it is altered to account for dwarf mistletoe with the following equation:

$$ADG = NDG \times DGP \times \frac{CL}{10}$$

where:

ADG	=	altered diameter growth, in inches
NDG	=	normal diameter growth, in inches
DGP	=	dwarf mistletoe diameter growth potential based on DMR (taken from Exhibit 2.9 where percent is converted to a decimal, or supplied using the MISTGMOD keyword)
CL	=	cycle length (converted from 10-year period to user input length)

The data used to formulate the relationship between DMR and diameter growth potential (Exhibit 2.9) are presented with sources in Exhibit 2.10 (all entries were translated from the original source into percent potential growth in 10 years and then averaged together for the model):

DMR	A (%)	B (%)	C (%)	D (%)	E (%)	F (%)	G (%)	H (%)	I (%)	J (%)	K (%)	L (%)
0	100	100	100	100	100	100	100	100	100	100	100	100
1	90	100	91	93	100	100	100	100	100	100	100	100
2	90	100	82	97	100	100	100	100	100	100	100	100
3	60	100	86	80	98	78	87	99	71	96	71	91
4	60	79	77	93	81	78	87	99	71	96	71	73
5	30	79	57	77	62	45	41	51	43	49	37	57
6	30	79	23	63	33	45	41	51	43	49	37	39

Sources:

A. Region 6 values (Knutson and Tinnin 1986; Pierce 1960)
B. Thinned Douglas-fir plots, Lolo Natl. Forest (MT) (Dooling *et al.* 1986)
C. Age 58-70 Douglas-fir stands, Malheur Natl. Forest (OR) (Knutson and Tinnin 1986)
D. Age 58-70 Douglas-fir stands, Okanogan Natl. Forest (WA) (Knutson and Tinnin 1986)
E. Thinned Douglas-fir plots, Malheur Natl. Forest (OR) (Tinnin 1988)
F. 0.0-5.9” DBH trees, Malheur Natl. Forest (Tinnin 1988)
G. 6.0-11.9” DBH trees, Malheur Natl. Forest (Tinnin 1988)
H. >12.0” DBH trees, Malheur Natl. Forest (Tinnin 1988)
I. Age 0-49 trees, Malheur Natl. Forest (Tinnin 1988)
J. Age 50-79 trees, Malheur Natl. Forest (Tinnin 1988)
K. Age >79 trees, Malheur Natl. Forest (Tinnin 1988)
L. Mixed-conifer stands, five national forests (AZ, NM) (Mathiasen *et al.* 1990)

Exhibit 2.10 Data and Sources for Exhibit 2.11.

Exhibit 2.10 is a graph of the diameter growth modification equation for Douglas-fir with mistletoe infection (black points) and the data used to formulate the relationship between DMR and diameter growth (white points).

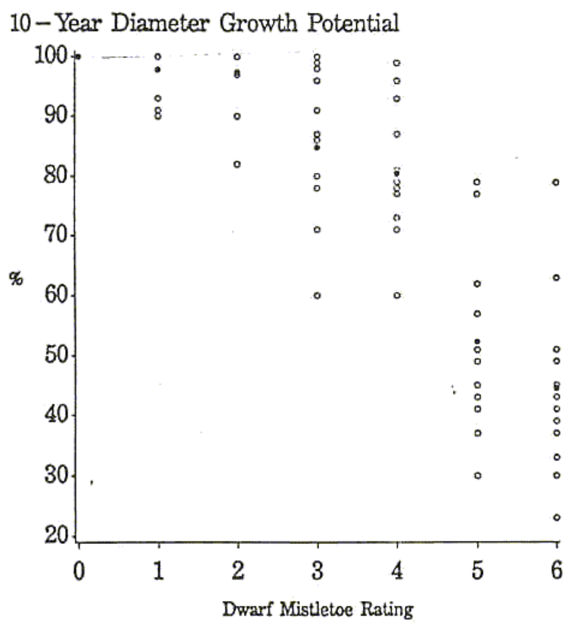

Exhibit 2.11 Douglas-fir diameter growth potential vs. DMR.

2.4.4 The True Fir Growth Modification Equation

This section includes the data used to build the true fir mistletoe growth modification equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The true fir diameter growth modification equation is based on the percentages listed in the table in Exhibit 2.12, which shows how growth potential corresponds to DMR:

DMR	0	1	2	3	4	5	6
10-year diameter growth potential (percent)	100	100	100	98	95	70	50

Exhibit 2.12 Relationship of true fir diameter growth potential to DMR..

Other species similarly affected by dwarf mistletoe which also use the true fir percentages are:

- red fir,
- white fir,
- alpine fir,
- grand fir,
- noble fir,
- pacific silver fir, and
- corkbark fir.

After diameter growth is calculated in FVS, it is altered to account for dwarf mistletoe with the following equation:

$$ADG = NDG \times DGP \times \frac{CL}{10}$$

where:

ADG	=	altered diameter growth, in inches
NDG	=	normal diameter growth, in inches
DGP	=	dwarf mistletoe diameter growth potential based on DMR (taken from Exhibit 2.12 where percent is converted to a decimal, or supplied by the MISTGMOD keyword)
CL	=	cycle length (converted from 10-year period to user input length

The data used to formulate the relationship between DMR and diameter growth potential (Exhibit 2.12) are presented with sources in Exhibit 2.13 (all entries were translated from the original source into percent potential growth in 10 years and then averaged together for the model):

DMR	Region 6 Values (1) (%)	Region 5 Values (2) (%)
0	100	100
1	100	100
2	100	100
3	95	100
4	90	100
5	55	85
6	50	50

Sources:
A. Unpublished data, R. Scharpf; Filip 1984.
B. Unpublished data, Dennis Hart

Exhibit 2.13 Data and Sources for Exhibit 2.12.

Exhibit 2.14 is a graph of the diameter growth modification equation for true fir with mistletoe infection (black points) and the data used to formulate the relationship between DMR and diameter growth (white points).

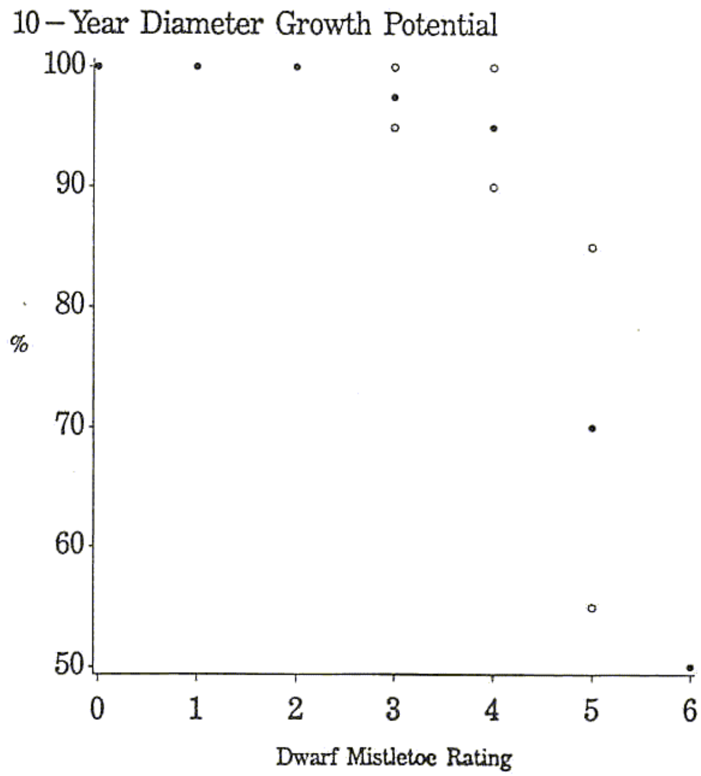

Exhibit 2.14 True fir diameter growth potential vs. DMR.

2.4.5 The Ponderosa Pine Growth Modification Equation

This section includes the data used to build the ponderosa pine mistletoe growth modification equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The ponderosa pine diameter growth modification equation is based on the percentages listed in the table in Exhibit 2.15, which shows how growth potential corresponds to DMR:

DMR	0	1	2	3	4	5	6
10-year diameter growth potential (percent)	100	100	100	98	86	73	50

Exhibit 2.15 Relationship of ponderosa pine diameter growth potential to DMR.

Other species similarly affected by dwarf mistletoe which also use the ponderosa pine percentages are:

- mountain hemlock,
- blue spruce, and
- Jeffrey pine.

After diameter growth is calculated in FVS, it is altered to account for dwarf mistletoe with the following equation:

$$ADG = NDG \times DGP \times \frac{CL}{10}$$

where:

ADG	=	altered diameter growth, in inches
NDG	=	normal diameter growth, in inches
DGP	=	dwarf mistletoe diameter growth potential based on DMR (taken from Exhibit 2.15, where percent is converted to a decimal, or supplied by the MISTGMOD keyword)
CL	=	cycle length (converted from 10-year period to user input length)

The data used to formulate the relationship between DMR and diameter growth potential (Exhibit 2.15) are presented with sources in Exhibit 2.16(all entries were translated from the original source into percent potential growth in 10 years and then averaged together for the model):

DMR	Region 6-Values (1) (%)	Age 55 Stand Mescalero-Apache, NM (2) (%)	Age 140 Stand Mescalero-Apache, NM (2) (%)	Grand Canyon, AZ (3) (%)
0	100	100	100	100
1	100	100	100	100
2	100	100	100	100
3	100	100	100	90
4	85	100	86	71
5	70	81	74	65
6	50	65	48	35

Sources:

A. Maffei 1989; Childs and Edgren 1967; and Shea 1964.
B. Hawksworth 1961.
C. Lighte and Hawksworth 1973.

Exhibit 2.16 Data and Sources for Exhibit 2.15.

Exhibit 2.17 is a graph of the diameter growth modification equation for ponderosa pine with mistletoe infection (black points) and the data used to formulate the relationship between DMR and diameter growth (white points).

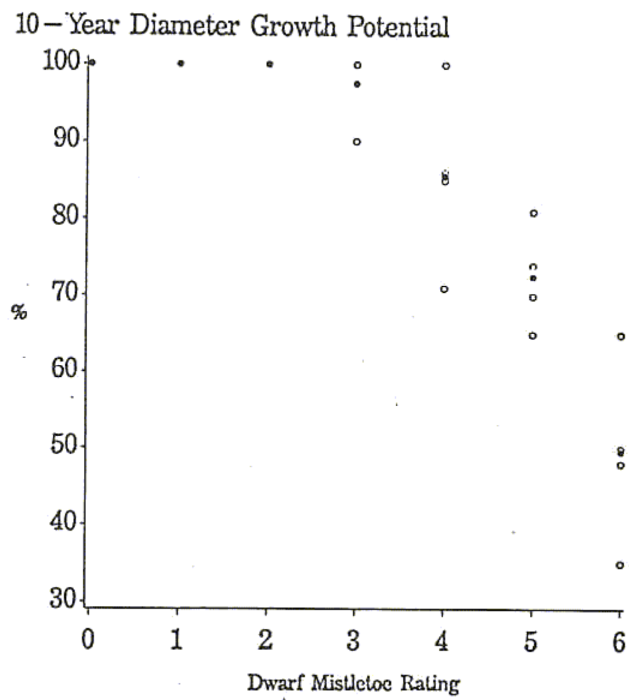

Exhibit 2.17 Ponderosa pine diameter growth potential vs. DMR.

2.5 How Height Growth is Modified

Height growth modification is species specific and based on DMR value. Users must provide impact proportion of height growth for each host species and DMR rating. At this time there are no default values present in the model.

Height growth impact in the model is implemented in much the same manner as the diameter growth impacts. Based on the tree species and the individual tree record dwarf mistletoe rating (DMR), the predicted height growth increment for the FVS growth cycle is reduced. The reduction in the height growth increment is accomplished by applying a proportion-of-normal multiplier. Dwarf mistletoe height growth impact proportion-of-normal values are stored in an array indexed by tree species and DMR. Valid height growth impact values range from 1.0 which translates to height growth unaffected to 0.0 which means all height growth has been suppressed. In FVS height growth is measured in feet and the minimum normal tree height growth allowed is 0.1 feet. So, even though total suppression of height growth may be specified in the dwarf mistletoe height growth impact array, it will not happen in a FVS simulation. Realistically speaking though, is 0.1 feet of height increment actual “growth”? Mathematically, it certainly is, but contrast that to the accuracy that tree height measurements are collected and recorded in the field.

The dwarf mistletoe related height growth impact occurs in the simulation process following the diameter growth calculation. Since the height increment determination by FVS uses diameter increment, the specific DM height growth impact values are not those that were directly measured in the field because the reduction in diameter increment has already resulted in some height growth loss due to the diameter to height relationships already in play in the process. DM height growth impact is coded in funtion form and included in the final height growth equation, HTG(I)=SCALE*XHT*HTG(I)**MISHGF()*, as an additional multiplier where I is the tree index number and mishgf() returns the DMR correlated proportion of 1 to 0.

The primary source for this addition to the model is:

Mallams, Katy 2007. Permanent plots for measuring spread and impact of Douglas-fir dwarf mistletoe in the Southern Oregon Cascades, Pacific Northwest Region: Results of the ten year remeasurement. USDA Forest Service, Pacific Northwest Region, Southwest Oregon Forest Insect and Disease Service Center, Central Point, Oregon. SWOFIDSC-07-04. 34 pp.

Note that in the above cited paper, the terminology of Broom Volume Rating (BVR) is used instead of the Frank Hawksworth Dwarf Mistletoe Rating (DMR) terminology. The same scale of 0-6 is used for both of these and so no translation is made in order to apply the finding reported in this paper to the Dwarf Mistletoe Impact Model. Since this modification has not been fully evaluated, there are no default values placed in the proportion of potential height growth array. The values in the array are all set to 1.00 which specifies no height growth impact. Height growth impact values are set by the MistHMod keyword (see the MISTHMOD keyword section of this manual). It is not expected the actual values that need to be set will be the direct values from the paper. The reason for this is the reduction in diameter growth that the DM model applies to any given tree record is going to have an indirect impact on the height growth; therefore, the height growth proportional impact will need to be scaled so that the modeled height growth impact reflects that which was derived from field measurements.

The baseline (Douglas-fir) height growth impacts by DMR from SWOFIDSC-07-04 were interpretted to form a smoother curve across the 6 ratings and can serve as reasonable initial values for the MISTHMOD keyword.

DMR	Proportion of Potential Ht Growth (adjusted)	Proportion of Potential Ht Growth (reported)
1	1.00	1.00
2	1.00	1.00
3	0.95	1.00
4	0.65	0.50
5	0.50	0.50
6	0.10	0.00

Exhibit 2.xx Height growth potential by DMR baseline values.

Only sample trees with a DMR of 1 or greater at the start of the cycle are considered to be infected. No change in tree growth is calculated by this model for sample trees that are not infected (DMR=0) at the start of the cycle.

See Appendix C for a list of tree species by FVS variant which are susceptible to height growth loss in the model due to dwarf mistletoe infection.

2.6 How Mortality is Calculated

There are four different mortality equations: one for lodgepole pine, one for ponderosa pine, one for Douglas-fir, and one for true firs. All other species whose mortality is affected by dwarf mistletoe infection are currently represented by one of these four equations.

Mortality caused by dwarf mistletoe is calculated in the DMIM system on a tree-by-tree basis. This mortality is determined using the following information for each tree: FVS variant, species, density of the stand (in trees per acre), DMR, cycle length, a site factor, DBH and a user input multiplier (if one was supplied). Using this information, the DMIM system calculates what percentage of the tree record would die due to the severity of the current mistletoe infection. This percentage is then compared with background mortality and the larger of the two values is retained as the mortality for that tree record in the current cycle. Mortality caused by dwarf mistletoe is generally larger than background mortality, especially in cases of severe infection, and this will be displayed in various forms in the mistletoe statistical output tables (discussed in later sections of this manual).

Probability of mortality of infected trees is calculated using a quadratic equation which was derived from a least-squares fit of individual tree mortality measured over 10 years, stratified by DMR. The data used in deriving the mortality equations were collected from across the western U.S. The mortality model equations and resulting 10-year percentages are presented by species in the following four sections. There is an equation to model each of these species: lodgepole pine, ponderosa pine, Douglas-fir, and true firs. Any other species native to a given area which is affected by mistletoe is emulated by one of the four models listed above, based on which species it is more closely related to in terms of how it is affected by mistletoe.

Only sample trees with a DMR of 1 or greater at the start of the cycle are considered infected. No change in mortality is calculated by this model for sample trees that are not infected (DMR=0) at the start of the cycle.

See Appendix C for a list of tree species, grouped by FVS variant, which are susceptible to dwarf mistletoe- induced mortality in the model.

2.6.1 The Lodgepole Pine Mortality Equation

This section includes the data used to build the lodgepole pine mistletoe mortality equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The 10-year mortality rate (in percent) for lodgepole pine with dwarf mistletoe infections is calculated with the following equation:

$$PM = (0.00112 + 0.0217\,DMR - 0.00171\,DMR^2) \times UIM \times 100$$

where:

PM	=	percent mortality due to mistletoe
DMR	=	dwarf mistletoe rating
UIM	=	user input multiplier (supplied using the MISTMORT keyword)

This rate is multiplied by 1.2 if the DBH of the tree is less than 9 inches. Upper bounds on percent mortality in a 10-year period due to mistletoe are set at 71% for trees with DBH less than 9 inches, and 50% for trees with DBH greater than or equal to 9 inches. The mortality probabilities are adjusted for cycle lengths other than 10 years.

This mortality percentage is then converted to TPA (trees per acre) and compared to background mortality to determine the larger of the two values. Other species similarly affected by dwarf mistletoe and also use the lodgepole pine mortality equation are:

- sugar pine;
- white pine;
- limber pine;
- whitebark pine; and
- western hemlock.

Resulting 10-year mortality percentages for lodgepole pine based on DMR and DBH are given in Exhibit 2.18.

DMR	**0**	**1**	**2**	**3**	**4**	**5**	**6**
% mortality, small trees (DBH <9 inches)	0.0	2.5	4.5	6.1	7.3	8.0	8.4
% mortality, large trees (DBH >=9 inches)	0.0	2.1	3.8	5.1	6.1	6.7	7.0

Exhibit 2.18 Lodgepole pine 10-year mortality percentages.

The data used to formulate the relationship between DMR and mistletoe mortality rates (Exhibit 2.18), and also used to generate the lodgepole pine mortality equation are presented with sources in Exhibit 2.19 (all entries were translated from the original source into 10-year percent mortality):

DMR	Region 6 Values(1) (%)	Study from Roosevelt (CO), Medicine Bow (WY), and Bighorn (WY) National Forests (2, 3) (%)
0	0.0	0.0
1	3.0	1.9
2	3.0	3.7
3	6.0	4.8
4	6.0	5.8
5	7.0	6.4
6	7.0	7.0

Sources:

A. Maffei and Hessburg, personal communication; and Hawksworth and Hinds 1964
B. Hawksworth and Johnson 1989
C. Hawksworth 1958

Exhibit 2.19 Data and Sources for Exhibit 2.18.

Exhibit 2.20 is a graph of the large-tree mortality equation for lodgepole pine with mistletoe infection (curve) and the data used to formulate the relationship between DMR and tree mortality (white points).

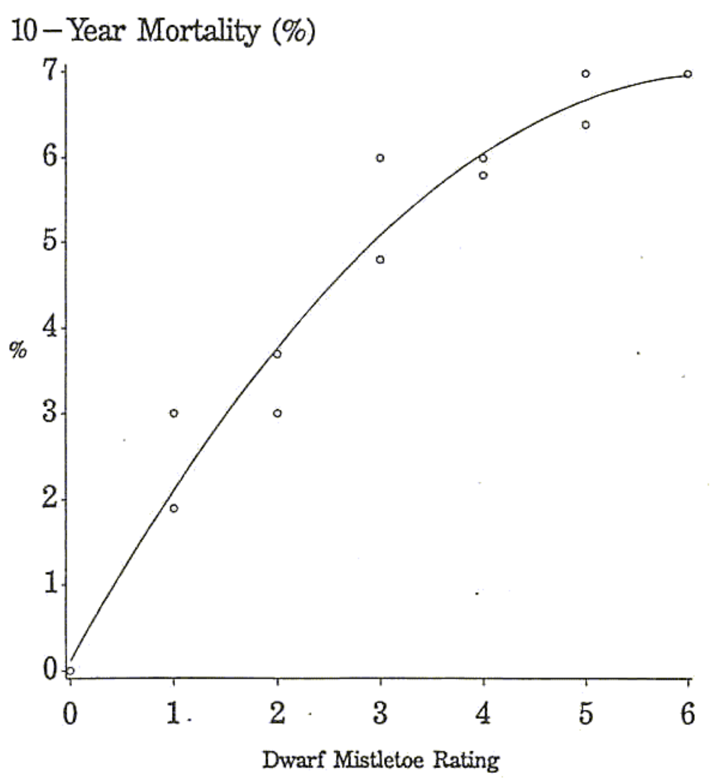

Exhibit 2.20 Lodgepole pine mortality vs. DMR.

2.6.2 The Ponderosa Pine Mortality Equation

This section includes the data used to build the ponderosa pine mistletoe mortality equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The 10-year mortality rate (in percent) for ponderosa pine with dwarf mistletoe infections is calculated with the following equation:

$$PM = (0.00681 - 0.00580\,DMR + 0.00935\,DMR^2) \times UIM \times 100$$

where:

PM	=	percent mortality due to mistletoe
DMR	=	dwarf mistletoe rating
UIM	=	user input multiplier (supplied using the MISTMORT keyword)

This rate is multiplied by 1.2 if the DBH of the tree is less than 9 inches. Upper bounds on percent mortality in a 10-year period due to mistletoe are set at 71% for trees with DBH less than 9 inches, and 50% for trees with DBH greater than or equal to 9 inches. The mortality probabilities are adjusted for cycle lengths other than 10 years.

This mortality percentage is then converted to TPA (trees per acre) and compared to background mortality to determine the larger of the two values. Other species that are similarly affected by dwarf mistletoe and also use the ponderosa pine mortality equation are:

- Jeffrey pine;
- blue spruce; and
- mountain hemlock.

Resulting 10-year mortality percentages for ponderosa pine based on DMR and DBH are given in Exhibit 2.21.

DMR	**0**	**1**	**2**	**3**	**4**	**5**	**6**
% mortality, small trees (DBH <9 inches)	0.0	1.2	3.9	8.8	16.0	25.4	37.0
% mortality, large trees (DBH >=9 inches)	0.0	1.0	3.3	7.4	13.3	21.2	30.9

Exhibit 2.21 Ponderosa pine 10-year mortality percentages.

The data used to formulate the relationship between DMR and mistletoe mortality rates (Exhibit 2.21), and also used to generate the ponderosa pine mortality equation are presented with sources in Exhibit 2.22 (all entries were translated from the original source into 10-year percent mortality):

DMR	A (%)	B (%)	C (%)	D (%)	E (%)	F (%)	G (%)
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	3.5	0.0	2.0	3.1	0.9	1.3	0.0
2	7.0	4.0	3.0	10.3	3.1	2.6	0.0
3	10.0	11.5	4.0	17.8	5.3	5.0	0.0
4	13.0	16.5	8.0	22.5	11.6	9.8	0.0
5	16.5	19.0	12.0	27.2	20.9	19.1	34.5
6	19.0	29.5	38.0	31.3	29.7	37.3	34.5

Sources:

A. 3053 plots in AZ and NM (Andrews and Daniels 1960)
B. South rim of Grand Canyon, AZ (Lightle and Hawksworth 1973)
C. 4013 plots on Mescalero-Apache Reservation, NM (Hawksworth and Lusher 1956)
D. 17.1 acres in Grand Canyon Natl. Park - small trees (Hawksworth and Geils 1990)
E. 17.1 acres in Grand Canyon Natl. Park - large trees (Hawksworth and Geils 1990)
F. CA and NV forest recreation areas (Scharpf *et al.* 1988)
G. Region 6 values (Maffei 1989; and Pringle Falls unpublished data, L.F. Roth)

Exhibit 2.22 Data and Sources for Exhibit 2.21.

Exhibit 2.23 is a graph of the large-tree mortality equation for ponderosa pine with mistletoe infection (curve) and the data used to formulate the relationship between DMR and tree mortality (white points).

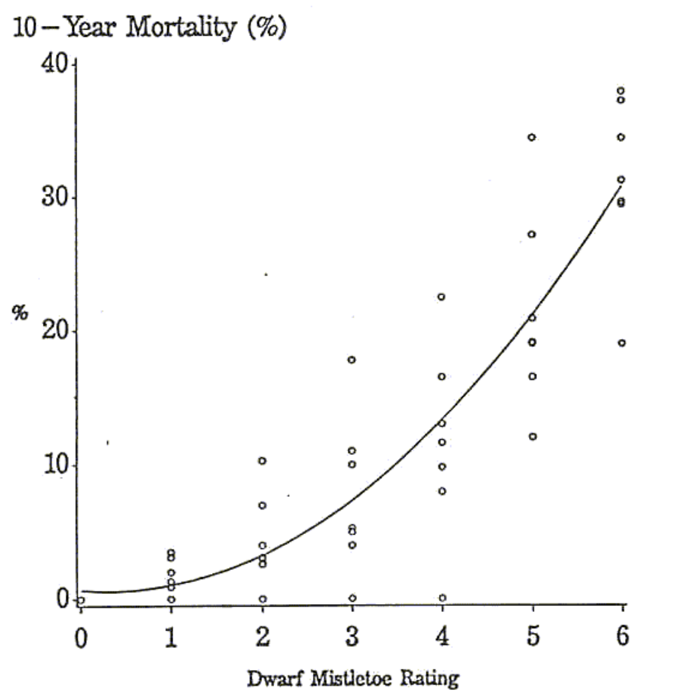

Exhibit 2.23 Ponderosa pine mortality vs. DMR.

2.6.3 The Douglas-Fir Mortality Equation

This section includes the data used to build the Douglas-fir mistletoe mortality equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The 10-year mortality rate (percent) for Douglas-fir with dwarf mistletoe infections is calculated with the following equation:

$$PM = (0.01319 - 0.01627\,DMR + 0.00822\,DMR^2) \times UIM \times 100$$

where:

PM	=	percent mortality due to mistletoe
DMR	=	dwarf mistletoe rating
UIM	=	user input multiplier (supplied using the MISTMORT keyword)

This rate is multiplied by 1.2 if the DBH of the tree is less than 9 inches. Upper bounds on percent mortality in a 10-year period due to mistletoe are set at 71% for trees with DBH less than 9 inches, and 50% for trees with DBH greater than or equal to 9 inches. The mortality probabilities are adjusted for cycle lengths other than 10 years.

This mortality percentage is then converted to TPA (trees per acre) and compared to background mortality to determine the larger of the two values. Other species that are similarly affected by dwarf mistletoe and also use the Douglas-fir mortality equation are:

- western larch;
- larch; and
- Engelmann spruce.

Resulting 10-year mortality percentages for Douglas-fir based on DMR and DBH are given in Exhibit 2.24.

DMR	**0**	**1**	**2**	**3**	**4**	**5**	**6**
% mortality, small trees (DBH <9 inches)	0.0	0.6	1.6	4.6	9.6	16.5	25.4
% mortality, large trees (DBH >=9 inches)	0.0	0.5	1.4	3.8	8.0	13.7	21.1

Exhibit 2.24 Douglas-fir 10-year mortality percentages.

The data used to formulate the relationship between DMR and mistletoe mortality rates (Exhibit 2.24), and also used to generate the Douglas-fir mortality equation are presented with sources in Exhibit 2.25 (all entries were translated from the original source into 10-year percent mortality):

DMR	A (%)	B (%)	C (%)	D (%)	E (%)	F (%)
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	1.0	---	5.1	2.0
2	0.5	0.0	1.0	6.4	9.4	3.0
3	0.0	0.0	1.0	6.5	4.0	8.0
4	0.6	0.0	1.4	19.2	15.4	12.0
5	3.0	2.4	7.9	21.0	5.1	23.0
6	9.8	10.5	7.9	29.1	38.5	44.0

Sources:

A. Northwest Douglas-fir, 2,269 trees (unpublished data, B. Geils)
B. Southwest Douglas-fir, 452 trees (unpublished data, B. Geils)
C. Region 6 values (Knutson and Tinnin 1986; Pierce 1960)
D. S.W. mixed conifer, 21,885 Douglas-fir trees (unpublished data, B. Geils)
E. S.W. mixed conifer, 441 5-year remeasured trees (unpublished data, B. Geils)
F. 4,013 plots on Mescalero-Apache Reservation, NM (Hawksworth and Lusher 1956)

Exhibit 2.25 Data and Sources for Exhibit 2.24.

Exhibit 2.26 is a graph of the large-tree mortality equation for Douglas-fir with mistletoe infection (curve) and the data used to formulate the relationship between DMR and tree mortality (white points).

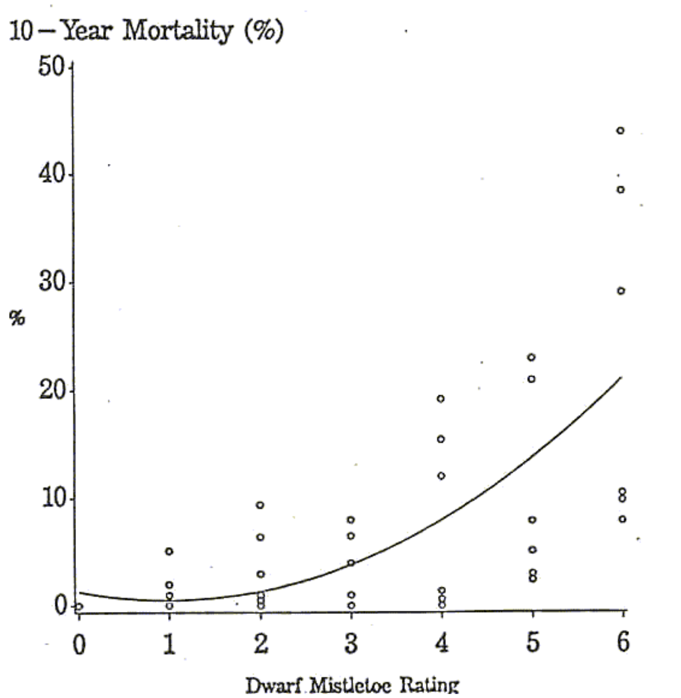

Exhibit 2.26 Douglas-fir mortality *vs.* DMR.

2.6.4 The True Fir Mortality Equation

This section includes the data used to build the true fir mistletoe mortality equation, which is also used to emulate other species similarly affected by dwarf mistletoe.

The 10-year mortality rate (in percent) for true firs with dwarf mistletoe infections is calculated with the following equation:

$$PM = (0.00159\,DMR + 0.00508\,DMR^2) \times UIM \times 100$$

where:

PM	=	percent mortality due to mistletoe
DMR	=	dwarf mistletoe rating
UIM	=	user input multiplier (supplied using the MISTMORT keyword)

This rate is multiplied by 1.2 if the DBH of the tree is less than 9 inches. Upper bounds on percent mortality in a 10-year period due to mistletoe are set at 71% for trees with DBH less than 9 inches, and 50% for trees with DBH greater than or equal to 9 inches.

This mortality percentage is then converted to TPA (trees per acre) and compared to background mortality to determine the larger of the two values. Other species that are similarly affected by dwarf mistletoe and also use the true fir mortality equation are:

- subalpine fir;
- grand fir;
- red fir;
- white fir;
- noble fir;
- Pacific silver fir; and
- corkbark fir.

Resulting 10-year mortality percentages for true firs based on DMR and DBH are given in Exhibit 2.27.

DMR	**0**	**1**	**2**	**3**	**4**	**5**	**6**
% mortality, small trees (DBH <9 inches)	0.0	0.8	2.8	6.1	10.5	16.2	23.1
% mortality, large trees (DBH >=9 inches)	0.0	0.7	2.3	5.0	8.8	13.5	19.2

Exhibit 2.27 True fir 10-year mortality percentages.

The data used to formulate the relationship between DMR and mistletoe mortality rates (Exhibit 2.27), and also used to generate the true fir mortality equation are presented with sources in Exhibit 2.28 (all entries were translated from the original source into 10-year percent mortality):

DMR	1281 Small Red/White Fir Trees in Lassen National Forest (%)
0	0.0
1	3.5
2	6.3
3	6.3
4	10.5
5	7.5
6	28.6

Source: unpublished data, D. Hart

Exhibit 2.28 Data and Sources for Exhibit 2.27.

Exhibit 2.29 is a graph of the small-tree mortality equation for true fir with mistletoe infection (curve) and the data used to formulate the relationship between DMR and tree mortality (white points).

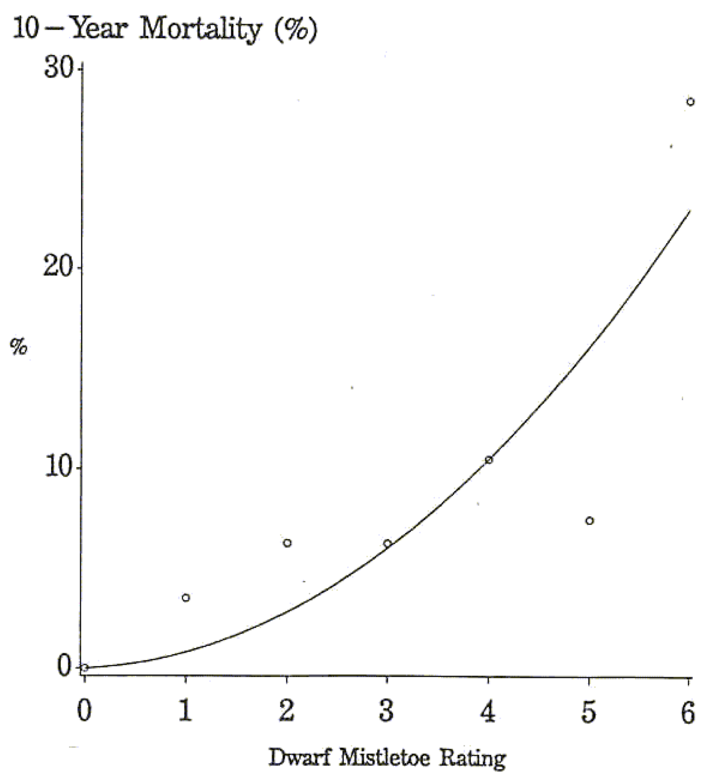

Exhibit 2.29 True fir mortality *vs.* DMR.

Chapter 3 - Using the Model

3.1 Accessing the Dwarf Mistletoe Model from FVS

Linked with the Dwarf Mistletoe Impact Modeling (DMIM) system, FVS will automatically use the dwarf mistletoe model to determine the effects of dwarf mistletoe infections, if present in the stand, for 17 different variants of FVS.

The DMIM system runs in conjunction with FVS for 17 different variants of FVS. The variants that are now available with dwarf mistletoe effects included are:

- Blue Mountains
- Central Idaho
- Central Rockies
  - Black Hills
  - Lodgepole Pine
  - Southwest Mixed Conifer
  - Southwest Ponderosa Pine
  - Spruce-Fir
- East Cascades
- Eastern Montana
- Inland California/Southern Cascades
- Kootenai/Kaniksu/Tally Lake (KooKanTL)
- Northern California (Klamath Mountains)
- Northern Idaho/Inland Empire (NI - 11 species)
- Northern Idaho/Inland Empire (IE - 23 species)
- Pacific Northwest Coast
- Southeast Alaska
- South Central Oregon/Northeast California
- Tetons
- Utah
- Western Sierra Nevada
- West Cascades

When the FVS and dwarf mistletoe models are linked, the effects of dwarf mistletoe will automatically be present in a run of FVS without having to do anything at all as long as mistletoe damage/severity codes are input with the tree data. Two output tables; the stand average summary table and the species-specific summary table, are automatically printed in the FVS main output file (see Section 3.3). In FVS, it is possible to have up to three pairs of damage/severity codes for each tree record, and any one of these pairs can be encoded with dwarf mistletoe damage/severity codes. Valid dwarf mistletoe 2-digit damage codes are as follows:

31 lodgepole pine mistletoe;

32 western larch mistletoe;

33 Douglas-fir mistletoe;

34 ponderosa pine mistletoe; and

30 dwarf mistletoe on any tree species.

Valid dwarf mistletoe severity codes are two-digit numbers ranging from 00 to 06, depending on the intensity of the infection (based on the Hawksworth 6-point Dwarf Mistletoe Rating Scale: Hawksworth 1977), where 00 implies no mistletoe infection anywhere on the tree, and 06 implies heavy mistletoe infection spread over the entire tree.

Another way to introduce dwarf mistletoe infections into a stand without having damage and severity codes in your tree-data file is to use the MISTPINF keyword. Use of this keyword will be covered in more detail in later sections of this manual along with other mistletoe-related keywords.

The sample tree-data file in Exhibit 3.1 shows how mistletoe infections are coded in the tree input data.

Codes:	**AAA**	**BBBB**	**C**	**DD**	**EE**	**F**	**GGHII**	**JJKK**	**LLL**
1	190 0 2	2000	1	LP	1	0 0	00 0		100 0
1	190 0 1	1000	1	LP	13	0 0	01 0		100 0
1	190 0 1	1000	1	LP	36	7 0	06 0		100 4
1	190 0 1	1000	1	LP	39	0 0	0073		100 0
1	190 0 1	1000	1	LP	48	0 0	03 0		100 5
1	190 0 1	282	1	LP	51	0 0	393 0	3101	100 1
1	190 0 1	261	1	LP	53	0 0	422 0	3102	100 1
1	190 0 1	261	1	LP	53	0 0	441 0	3103	100 0
1	190 0 1	252	1	LP	54	0 0	422 0	3104	100 0
1	190 0 1	121	1	LP	55	0 0	380 0	3105	100 0
1	190 0 1	226	1	LP	57	0 0	413 0	3106	100 2
1	190 0 1	226	1	LP	57	6 0	413 0		100 0
1	190 0 1	218	1	LP	58	0 0	461 0		100 0
1	190 0 1	204	1	LP	60	0 0	47173		100 0
1	190 0 1	71	1	LP	72	0 0	430 0		100 0

Designator codes:

A = Plot identification
B = Tree count (trees per 10 acres)
C = Tree history code
D = Species
E = DBH (tenths of inches)
F = Diameter increment (tenths of inches)
G = Height (in feet)
H = Crown ratio code
I = Tree damage code
J = Mistletoe damage code
K = DMR
L = Tree value code

Exhibit 3.1 An example of how mistletoe infections are coded in the tree input data.

Please refer to the User's Guide to the Stand Prognosis Model (Wykoff *et al*. 1982, and Wykoff *et al*. 1991) for details on running FVS, including how to set up keyword files and tree data files. The example above includes six lodgepole pine tree records with mistletoe infections ranging from DMR 1 to DMR 6.

The labels are based on the TREEFMT (tree-format) keyword codes shown in Exhibit 3.2 on the following page.

3.2 Using Keywords to Tailor the Model to Your Application

With keywords, you can alter the level of impact dwarf mistletoe will have upon a tree, alter the form and presence of statistical output tables, or tell the model to ignore the effects of dwarf mistletoe altogether.

Even though the DMIM system will run from FVS automatically without the help of any mistletoe keywords, sometimes it is necessary to modify the functionality of the mistletoe model to tailor it to your needs. This is where the dwarf mistletoe impact model keywords will come into play. Mistletoe keywords can be used to alter the behavior of processes such as mistletoe spread and intensification, growth modification, and mortality rates. They can also be used to alter cutting preference to remove mistletoe-infected trees, switch the printing of mistletoe statistical output tables on or off, introduce mistletoe infections into a stand, and indicate whether or not to ignore the effects of dwarf mistletoe altogether.

These options are covered in more detail in the following sections that describe the individual keywords, including definitions, valid input ranges, default values, variant and species-specific options, and examples of each. Mistletoe keywords and their subsequent input values must be included in the same file as other FVS keywords and are set apart from other FVS keywords with the use of the MISTOE and END keywords. Mistletoe keywords begin with the letters MIST. Each keyword requires a line of its own in the FVS keyword file. The keyword itself must be the first item on the line (blank filled up to 10 spaces). It may be followed by 0 to 7 fields, where each field is also 10 spaces long and is right justified in the field. The keywords that allow subsequent lines of input in the keyword file will be noted as such.

If the database (DBS) extension (Crookston and Gammel 2003) is present, the DBS MISRPTS keyword can be used to direct any selected mistletoe output to database tables in addition to, or instead of, the FVS main output file. (See Section 3.3 for further details.)

Exhibit 3.2 is an example of a FVS keyword file, including a block of mistletoe keywords.

```
STDIDENT
2404-0
DESIGN          0       1    99.9      16
STDINFO       601     999      60       0       1      51      47
INVYEAR      1980
BAMAX                                         587
TREEFMT
(T16,I4,T70,I1,T25,F5.1,I2,T34,A3,F3.1,F2.1,
T45,F3.0,T70,F3.0,T70,F3.1,T48,I1,6I2,I3,T70,I1,T58,I1)
NUMCYCLE
MISTOE
MISTPREF     1980       7       4
MISTPREF     2000       7       0
MISTMULT     1990      10     1.5       1
MISTMULT     2010      10       1       1
MISTMORT     2040       7     1.8
MISTMORT     2050       7       1
MISTGMOD     2040       7     .75
MISTGMOD     2050       7       1
MISTPINF     2000       4     .50       2       0
MISTPINF     2000       7     .25       4       0
MISTPRT      2080       1
MISTPRT      2100       0
MISTABLE     1990       4
MISTABLE     1990       7
MISTABLE     2000       4
MISTABLE     2000       7
MISTABLE     2010       4
MISTABLE     2010       7
END
PROCESS
STOP
```

Exhibit 3.2 An example of an FVS keyword file, including a block of mistletoe keywords.

Please refer to the User's Guide to the Stand Prognosis Model (Wykoff *et al*. 1982) for more information on setting up and executing FVS keyword files. The example above includes a block of mistletoe keywords beginning with the MISTOE keyword and ending with the END keyword.

3.2.1 Using the MISTOE/END Keywords

The MISTOE/END keywords signal the FVS keyword reader that dwarf mistletoe model keywords are present.

These keywords signal that mistletoe extension keywords are present. Mistletoe extension keywords can be used to alter embedded mistletoe spread and intensification, growth modification, and mortality rates. They are also used to alter cutting preference to remove mistletoe-infected trees, switch on and off the printing of mistletoe output tables, alter the destination of mistletoe output tables, introduce mistletoe infections in a stand, and indicate whether or not to ignore the effects of mistletoe altogether.

The MISTOE/END keywords do not have any associated fields.

Note: The mistletoe extension keyword sequence *must* begin with the MISTOE keyword and end with the END keyword. All keywords contained within this sequence are considered mistletoe keywords. In total, the valid mistletoe keywords are:

MISTOE/END			
MISTABLE	MISTGMOD	MISTMORT	MISTMULT
MISTOFF	MISTPINF	MISTPREF	MISTPRT

Exhibit 3.3 is an example of a MISTOE keyword segment.

```
MISTOE
MISTPREF        1980         7         4
MISTPREF        2000         7         0
MISTMULT        1990        10       1.5         1
MISTMULT        2010        10         1         1
MISTMORT        2040         7       1.8
MISTMORT        2050         7         1
MISTGMOD        2040         7       .75
MISTGMOD        2050         7         1
MISTPINF        2000         4       .50         2         0
MISTPINF        2000         7       .25         4         0
MISTPRT         2080         1
MISTPRT         2100         0
MISTABLE        1990         4
MISTABLE        1990         7
MISTABLE        2000         4
MISTABLE        2000         7
MISTABLE        2010         4
MISTABLE        2010         7
END
```

Exhibit 3.3 An example of a MISTOE keyword segment.

The MISTOE keyword is used in this example to signal that all keywords following will be mistletoe-related, until an END keyword is encountered.

3.2.2 Using the MISTOFF Keyword

Use this keyword to direct the model to ignore all effects of dwarf mistletoe.

This keyword directs FVS and the DMIM system to ignore all effects of dwarf mistletoe, whether or not any are present in the stand (i.e. run as if the stand is not infected). The MISTOFF keyword is only valid between a MISTOE and an END keyword. Only one MISTOFF keyword may be used per sequence.

The MISTOFF keyword does not have any associated fields.

The model defaults to processing with the effects of dwarf mistletoe in the absence of this keyword, when there is at least one tree record with a mistletoe infection. MISTOFF does not override other keywords: it only ignores the effects of mistletoe infections in the initial stand data. You may use this keyword to remove the effects of mistletoe from a stand without having to edit (sometimes) large numbers of FVS tree data input records. The model continues to function, and new infections may be introduced with the MISTPINF keyword.

Exhibit 3.4 is an example of a MISTOFF keyword segment.

```
MISTOE
MISTOFF
END
```

Exhibit 3.4 An example of a MISTOFF keyword segment.

In this example, all effects of dwarf mistletoe are turned off for this run of FVS, even if mistletoe damage and severity codes are present in the tree data input file.

3.2.3 Using the MISTPREF Keyword

The MISTPREF keyword is used to alter the removal preference of dwarf mistletoe-infected trees.

This keyword adds removal preference values based on DMR to previously computed values based on other factors, tree-by-tree, before certain thinning keywords (THINABA, THINATA, THINBBA, THINBTA) are applied. These other factors include species, tree condition, and DBH. Once an overall preference for each tree is computed, trees with the highest preference values are cut first, until cutting targets are reached. This keyword does not affect the use of the THINDBH keyword (see the *Users Guide to the Stand Prognosis Model* or *Essential FVS: A User's Guide to the Forest Vegetation Simulator*). This keyword is only valid between a MISTOE and END keyword. More than one MISTPREF keyword may be used per sequence.

field 1: Date (calendar year or cycle number) in which removal preference change is implemented. The change remains in effect until replaced by a subsequent preference change. Range: 4-digit calendar year or 0 to 40 for cycle number. A "0" will cause the activity to be performed in every cycle.

field 2: Species abbreviation or number whose removal preference is to be changed.

Fields 3-7 are not used.

Required Supplemental Record: Preference values for DMR 1, DMR 2, and so on, through DMR 6. Format: Six numeric values are required starting in any column and separated by blanks. Range: none.

Defaults by fields:

Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**
All Variants	all	*	not used	not used	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a "0"; which will default to all species in the variant, listed in Exhibit 3.5.

Variant	**Affected by Mistletoe**	**Not Affected by Mistletoe**
SE Alaska (AK)	SF, WH,LP,AF	MH,WS,RC,YC,SS,RA,CW,OH,OS
Blue Mountains (BM)	WL,DF,LP,PP,WB,LM	WP,GF,MH,WJ,ES,AF,PY,YC,AS,CW, OS,OH
Inland California / Southern Cascades (CA)	WF,RF,SH,DF,WH,MH,WB,KP, LP,LM,JP,SP,WP,PP	PC,IC,RC,CP,MP,GP,JU,BR,GS,PY,OS, LO,CY,BL,EO,WO,BO,VO,IO,BM,BU, RA,MA,GC,DG,FL,WN,TO,SY,AS,CW, WI,CN, CL,OH
Central Idaho (CI)	WP,WL,DF,GF,LP,AF,PP,WB,LM	WH,RC,ES,PY,AS,WJ,MC,CW,OS,OH
Central Rockies (CR)	AF,CB,DF,GF,WF,MH,WL,BC, LM,LP,PI,PP,WB,SW,BS,ES, PM,PD,AZ,CI	RC,UJ,WS,AS,NC,PW,GO,AW,EM,BK, SO,PB,AJ,RM,OJ,ER,OS,OH
East Cascades (EC)	WP,WL,DF,SF,GF,LP,AF,PP,WH, MH,NF,WF	RC,ES,PY,WB,LL,YC,WJ,BM,VN,RA,PB, GC,DG,AS,CW,WO,PL,WI,OS,OH
Eastern Montana (EM)	WB,DF,LP	L,S,AF,PP,OT
KooKanTL (KT)	L,DF,LP,PP	WP,GF,WH,C,S,AF,OT
Klamath Mountains (NC)	SP,DF,WF,RF,PP	OC,M,IC,BO,TO,OH
Northen Idaho / Inland Empire - 11 species (NI) - 23 species (IE)	 L,DF,LP,PP WL,DF,LP,PP,WB,LM	 WP,GF,WH,C,S,AF ,OT WP,GF,WH,RC,ES,AF,MH,LL, PI,JU,PY,AS,CO,MM.PB,OH,OS
Pacific Northwest Coast (PN)	AF,RF,LP,DF,WH,MH	SF,WF,GF,SS,NF,YC,IC,ES,JP,SP,WP, PP,RW,RC,BM,RA,WA,PB,GC,AS,CO, WO,J,LL,WB,KP,PY,DG,HT,BC,WI
SORNEC (SO)	WP,SP,DF,WF,LP,AF,PP,MH,SH, GF,SF,NF,WB,WL,WH	BM,AS,CW,CH,WO,WI,GC,MC, MB,RC,PY,RA,WA,IC,ES,JU,OS,OH
Tetons (TT)	WB,LM,DF,PM,BS,LP,AF,PP	AS,ES,UJ,RM,BI,MM,NC,MC,OS,OH
Utah (UT)	WB,LM,DF,WF,BS,LP,ES,AF,PP, PI,PM,GB	AS,WJ,GO,RM,UJ,NC,FC,MC,BI,BE,OS, OH
West Cascades (WC)	SF,WF,GF,AF,RF,NF,LP,WP,PP, DF,WH,MH,KP	YC,IC,ES,JP,SP,RW,RC,BM,RA,WA, PB,GC,AS,CW,WO,J,LL,WB,PY,DG, HT, BC,WI,OT
WESSIN (WS)	SP,DF,WF,JP,RF,PP,LP,WB, WP,PM,SF,KP,FP,CP,LM,MP, GP,WE,GB,BD,MH	GS,IC,RW,WJ,UJ,CJ,LO,CY,BL,BO,VO, IO,TO,GC,AS,CL,MA,DG,BM,MC,OS,OH

Exhibit 3.5 Species defaults by variant.

Exhibit 3.6 is an example of a MISTPREF keyword segment.

```
MISTOE
MISTPREF        1980         7
       0      0      0      4000   5000   6000
MISTPREF        1990         3
       0      0      0      0      0      6000
MISTPREF        2000         ALL
       0      0      0      0      0      0
END
```

Exhibit 3.6 An example of a MISTPREF keyword segment.

In this example, beginning in 1980, trees of species 7 will be removed by cutting trees with DMR 6 first, DMR 5 next, and then DMR 4. Trees with DMR of 3 or less will be cut last, and differences in DMR will not affect the cutting preferences of these trees.

In the year 1990, trees of species 3 with DMR=6 will have very high preferences. This would be combined with a reduced cutting efficiency (using, for example, a value of 0.50 in a THINABA or THINATA keyword, so that some DMR 6 trees would be retained for special wildlife habitat.

In the year 2000, the cutting preference for all species will be set back to 0, meaning that there will be no removal preference due to mistletoe from the year 2000 on.

3.2.4 Using the MISTGMOD Keyword

The MISTGMOD keyword is used to alter the existing effects of dwarf mistletoe on diameter growth.

This keyword provides diameter growth modification values by DMR classes. Diameter growth modifiers are real number values representing proportional loss of diameter growth due to mistletoe infection based on the intensity of the infection for that tree. This keyword is only valid between a MISTOE and an END keyword. More than one MISTGMOD keyword may be used per sequence.

field 1: Date (calendar year or cycle number) in which diameter growth proportions are applied. The proportions remain in effect until replaced by subsequent proportions. Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.

field 2: Species abbreviation or number to which proportions are applied.

Fields 3-7 are not used.

Supplemental Record:

Diameter growth modification proportions by DMR for the cycle and species listed above. Format: Six real numbers are required, starting in any column and separated by blanks, the first for DMR=1, the second for DMR=2, and so on. Range: 0.0 to 1.0; a value near 0.0 causes extreme diameter growth impact and a value of 1.0 causes no diameter growth impact.

Defaults by fields:

Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**
All variants	1	*	not used	not used	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0”, which will default to all species in the variant, listed in Exhibit 3.5.

Exhibit 3.7 is an example of a MISTGMOD keyword segment.

```
MISTOE
MISTGMOD         1990           7
1.0    1.0    1.0    .83    .65    .49
END
```

Exhibit 3.7 An example of a MISTGMOD keyword segment.

In this example, beginning in 1990, trees of species 7 with a DMR of 6 will have only 49 percent of normal diameter growth due to dwarf mistletoe infection. The same species with a DMR of 5 will have 65 percent of normal growth, and DMR 4 trees will have 83 percent of normal diameter growth. The trees with DMR values of 1 to 3 will experience no diameter growth impact due to dwarf mistletoe infections.

3.2.5 Using the MISTHMOD Keyword

The MISTHMOD keyword is used to add effects of dwarf mistletoe on height growth. There are no default values set in the model for this keyword; therefore, if the user desires additional height growth impact, the MISTHMOD keyword must be used.

This keyword provides height growth modification values by DMR classes. Height growth modifiers are real number values representing proportional loss of height growth due to mistletoe infection based on the intensity of the infection for that tree. This keyword is only valid between a MISTOE and an END keyword. More than one MISTHMOD keyword may be used per sequence.

field 1: Date (calendar year or cycle number) in which height growth proportions are applied. The proportions remain in effect until replaced by subsequent proportions. Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.

field 2: Species abbreviation or number to which proportions are applied.

Fields 3-7 are not used.

Supplemental Record:

Height growth modification proportions by DMR for the cycle and species listed above. Format: Six real numbers are required, starting in any column and separated by blanks, the first for DMR=1, the second for DMR=2, and so on. Range: 0.0 to 1.0; a value near 0.0 applies extreme height growth impact and a value of 1.0 applies no height growth impact.

Defaults by fields:

Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**
All variants	1	*	not used	not used	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0”, which will default to all species in the variant, listed in Exhibit 3.5.

Exhibit 3.8 is an example of a MISTHMOD keyword segment.

```
MISTOE
MISTHMOD         1990           7
1.0    1.0    .95    .65    .50    .10
END
```

Exhibit 3.8 An example of a MISTHMOD keyword segment.

In this example, beginning in 1990, trees of species 7 with a DMR of 6 will have only 10 percent of normal height growth due to dwarf mistletoe infection. The same species with a DMR of 5 will have 50 percent of normal growth, DMR 4 trees will have 65 percent and DMR 3 trees will have 95 percent of normal height growth. Trees of species 7 with DMR values of 1 and 2 will experience no height growth impact due to dwarf mistletoe infections.

3.2.6 Using the MISTMULT Keyword

The MISTMULT keyword is used to alter existing mistletoe spread and intensification probabilities.

This keyword provides multipliers that can be used to alter the default rate of dwarf mistletoe spread and intensification through a stand. This keyword is only valid between a MISTOE and an END keyword. More than one MISTMULT keyword may be used per sequence.

- field 1: Date (calendar year or cycle number) in which multipliers are applied. A multiplier remains in effect until replaced by a subsequent multiplier. Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.
- field 2: Species abbreviation or number to which multiplier is applied.
- field 3: Multiplier for changing the probability of DMR increasing. A value greater than 1 will increase this probability, and a value of less than 1 will decrease this probability. Range: greater than 0.
- field 4: Multiplier for changing the probability of DMR decreasing value greater than 1 will increase this probability, and less than 1 will decrease this probability. Range: greater than 0.

Fields 5-7 are not used.

Defaults by fields:

Variants	**1**	**2**	**3**	**4**	**5**	**6**	**7**
All Variants	all	*	1	1	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0”, which will default to all species in the variant, listed in Exhibit 3.5.

Exhibit 3.9 is an example of a MISTMULT keyword segment.

```
MISTOE
MISTMULT        1990         7       2.0       0.5
MISTMULT        1990        10       0.5       2.0
MISTMULT        2080         7         1         1
MISTMULT        2080        10         1         1
END
```

Exhibit 3.9 An example of a MISTMULT keyword segment.

In this example, the probability of a DMR increase will be multiplied by a factor of 2 for species 7 for all cycles between 1990 and 2080, while the probability of a DMR decrease will be lowered by a factor of 0.5. For species 10, the probability of a DMR increase will drop by a factor of 0.5 and probability of a DMR decrease will be multiplied by a factor of 2 during this same interval. From the year 2080 on, the probability of DMR increase and decrease for both species will return to normal.

3.2.7 Using the MISTMORT Keyword

The MISTMORT keyword is used to alter the existing percentage of mortality on a tree record due to dwarf mistletoe infection.

This keyword provides a multiplier used to alter mistletoe mortality. This keyword is only valid between a MISTOE and an END keyword. More than one MISTMORT keyword may be used per sequence.

field 1: Date (calendar year or cycle number) in which multipliers are applied. A multiplier remains in effect until replaced by a subsequent multiplier. Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.

field 2: Species abbreviation or number to which multiplier is applied.

field 3: Multiplier for changing mistletoe mortality; greater than 1 will increase mortality rate, and less than 1 will decrease mortality rate. Range: greater than 0.

Fields 4-7 are not used.

Defaults by fields:

Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**
All variants	all	*	1	not used	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0” , which will default to all species in the variant, listed in Exhibit 3.5.

Exhibit 3.10 is an example of a MISTMORT keyword segment.

```
MISTOE
MISTMORT        1990                 1.5
MISTMORT        2000                 1.0
MISTMORT        2080        10      1.25
END
```

Exhibit 3.10 An example of a MISTMORT keyword segment.

In this example, mistletoe mortality will be 1.5 times larger than normal in cycle 1990 for all species affected by mistletoe in the current variant. If the variant is SORNEC, for example, this would affect these eight species: WP, SP, DF, WF, MH, LP, RF, and PP. Mistletoe mortality will then return to normal for all these species from the year 2000 on, except for species 10 (which in SORNEC is PP: ponderosa pine) which will have mistletoe mortality increased 1.25 times from cycle 2080 through the last cycle.

3.2.8 Using the MISTABLE Keyword

The MISTABLE keyword is used to produce the detailed species/DBH (diameter breast height) class table, which is not produced automatically.

Use this keyword to produce detailed mistletoe output tables stratified by species and DBH-class, for a particular year or cycle. Output is printed to the FVS main output file. This keyword is only valid between a MISTOE and an END keyword. More than one MISTABLE keyword may be used per sequence. There is currently no option to allow this information to be placed in a database table.

field 1: Date (calendar year or cycle number) in which to print detail taken. The tables will be printed in this cycle only (does not carry over to subsequent cycles). Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.

field 2: A valid 2-character species abbreviation or number.

Fields 3-7 are not used.

Defaults by fields:

Variant	1	2	3	4	5	6	7
All variants	1	*	not used	not used	not used	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0”, which will default to all species in the variant, listed in Exhibit 3.5.

Exhibit 3.11 is an example of a MISTABLE keyword segment.

```
MISTOE
MISTABLE        1990        4
MISTABLE        1990        7
MISTABLE        1990       10
MISTABLE        2080
END
```

Exhibit 3.11 An example of a MISTABLE keyword segment.

In this example, in cycle 1990, mistletoe species/DBH class detail tables will be generated for species 4, 7, and 10. Then, in cycle 2080, the mistletoe species/DBH class tables will be generated for all species affected by mistletoe for the current variant. If the variant is SORNEC, for example, then there will be a table generated in this cycle for each of the following species: WP, SP, DF, WF, MH, LP, RF, and PP.

3.2.9 Using the MISTPRT Keyword

The MISTPRT keyword requests the dwarf mistletoe diameter class table.

Use this keyword to generate the mistletoe diameter class table. This keyword is only valid between a MISTOE and an END keyword. Only one MISTPRT keyword may be used per sequence. More information about the content of the output file is found in Section 3.3.3. If the database extension is present, the DBS MISRPTS keyword can be used to direct this output to a database table called FVS_DM_Sz_Sum in addition to, or instead of, the FVS main output file. (See Exhibit 3.17, Section 3.3.3 and the DBS extension documentation (Crookston and Gammel 2003) for further details.)

If the keyword is present the diameter class table will be written; otherwise the table will not be written. Note that the species/DBH class table is requested using the MISTABLE keyword.

field 1: Lower threshold DBH in inches for trees to be counted in DMI/DMR statistics. Smaller trees will be ignored during these calculations. Range: greater than or equal to 0.

Fields 2-7 are not used.

Defaults by fields:

Variant	1	2	3	4	5	6	7
All variants	1.0	not used	not used	not used	not used	not used	not used

Exhibit 3.12 is an example of a MISTPRT keyword segment.

```
MISTOE
MISTPRT            1.0
END
DATABASE
DSNOUT
test.xls
MISRPTS
END
```

Exhibit 3.12 An example of a MISTPRT keyword segment, including use of the MISRPTS keyword of the database extension, to also write the output to a table in an Excel file.

In this example, the diameter class summary table will be written to the standard FVS output file as well as to a Microsoft Excel spreadsheet. Dwarf mistletoe in trees with DBH less than 1.0 inch will be ignored. DMI and DMR ratings in the statistical output tables will reflect only trees with DBH greater than or equal to 1.0 inch.

3.2.10 Using the MISTPINF Keyword

The MISTPINF keyword is used to automatically introduce mistletoe infections into a proportion of trees in a stand.

Use this keyword to automatically introduce dwarf mistletoe infections to a proportion of trees in the stand (based on individual species in the stand) that were not already infected. This keyword is only valid between a MISTOE and an END keyword. More than one MISTPINF keyword may be used per sequence.

field 1: Date (calendar year or cycle number) in which infections are to be introduced. The infection will happen in this cycle only (does not carry over to subsequent cycles). Range: 4-digit calendar year or 0 to 40 for cycle number. A “0” will cause the activity to be performed in every cycle.

field 2: Species abbreviation or number to be infected.

field 3: Proportion of that species to be infected (not including already infected trees). Range: 0.0 to 1.0.

field 4: Level of infection for that species:
- 1 = all selected trees will start with DMR 1
- 2 = all selected trees will start with DMR 1 or 2
- …
- 6 = all selected trees will start with DMR 1, 2, 3, 4, 5, or 6

field 5: Method of infection for the stand:
- 0 = random infection throughout the species
- 1 = infection assigned beginning with the tallest and moving to the shortest trees
- 2 = infection assigned beginning with the shortest and moving to the tallest trees.

Fields 6-7 are not used.

Defaults by fields:

Variant	1	2	3	4	5	6	7
All variants	all	*	0	1	0	not used	not used

* Field 2 requires a valid 2-character species code; a valid numeric code; or a “0”, which will default to all species in the variant, listed in Exhibit 3.5.

If more than one MISTPINF keyword is to be used with different species in the same cycle, then the same method of infection must appear on each keyword for that cycle or it will default to the first method encountered. In other words, if species 7 is to be infected from tallest to shortest in the first cycle, then species 10 must also be infected from tallest to shortest in the first cycle. This is because method of infection requires that the entire treelist be sorted in a certain manner (either by height or randomly) so it cannot be done a different way for each species in the same cycle.

Exhibit 3.13 shows an example of a MISTPINF keyword segment.

```
MISTOE
MISTPINF        1990         7        .50          2          0
MISTPINF        1990        10        .25          4          0
MISTPINF        2000         4        .25          3          1
MISTPINF        2000         5        .10          6          1
END
```

Exhibit 3.13 An example of a MISTPINF keyword segment.

In this example, in the year 1990, 50% of the total number of not-yet-infected trees of species 7 will be infected randomly with DMR of 1 and 2. In the same cycle, 25% of all uninfected trees of species 10 will be infected randomly with DMR ranging from 1 to 4. Then, in the next cycle, 25% of uninfected species 4 trees will be infected with DMR of 1, 2, or 3, starting with the tallest trees and moving toward the shortest trees of that species. Also in the year 2000, not-yet-infected species 5 trees will be infected with DMR ranging from 1 to 6, starting with the tallest trees and moving toward the shortest trees until 10% of these are infected with mistletoe.

3.3 Producing Dwarf Mistletoe Statistical Output Tables

Two dwarf mistletoe impact output tables will automatically be produced with every run of FVS linked to the DMIM system. Keywords provide the ability to create two further tabular reports. Additional output is available when the spatial spread and intensification model is used.

When dwarf mistletoe is present in the inventory, the DMIM will automatically create and append two dwarf mistletoe output tables to the FVS main output file: a stand average summary table and a species-specific summary table. These two tables will be created even if the mistletoe keywords are not present. Other tabular and database reports can be produced using the MISTPRT and keywords, as shown in Exhibit 3.14. Tables will not be produced if mistletoe is absent.

Table Name	Section	Keyword	Database Table Name	Notes
Stand average	3.3.1	Automatic	FVS_DM_Stnd_Sum	Infection and mortality averaged over the entire stand
Species-specific	3.3.2	Automatic	FVS_DM_Spp_Sum	Infection and mortality grouped by species for the four most-infected species in the stand
Diameter class	3.3.3	MISTPRT	FVS_DM_Sz_Sum	Infection and mortality grouped by 2-inch DBH class from 0 to 20 inches
Species/DBH class	3.3.4	MISTABLE	(not available)	Infection and mortality stratified by cycle, species, and 2-inch DBH class.

Exhibit 3.14 The output tables available with the DMIM.

Please refer to the FVS Sequence of Events table (Exhibit 3.15) to understand where in each cycle the mistletoe statistical output information is gathered, calculated, and printed out. Exhibit 3.15 duplicates Exhibit 2.2, but is repeated here for ease of reference. The following sections should help in understanding and interpreting the mistletoe infection and mortality information presented in each table.

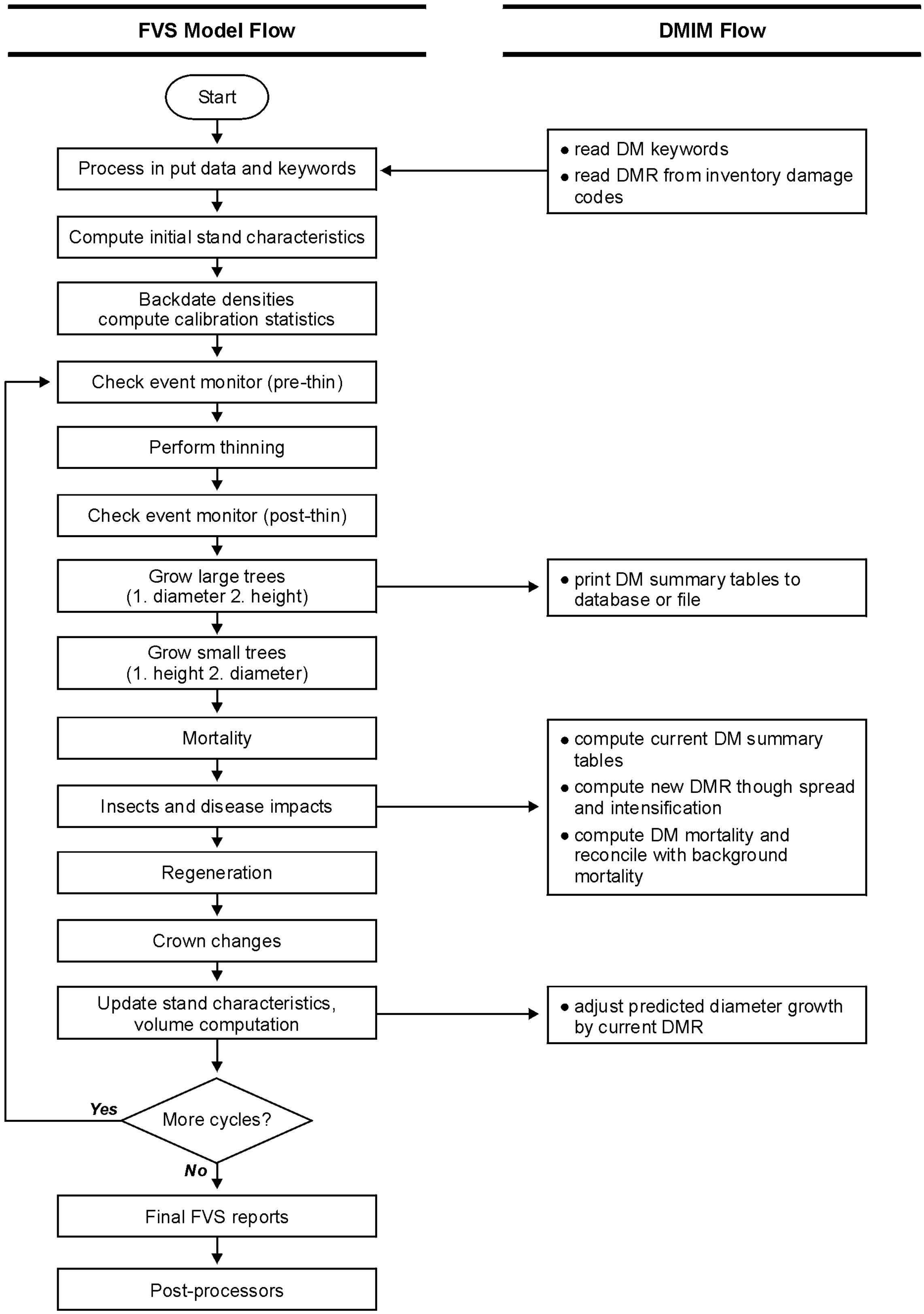

Exhibit 3.15 The sequence of events within FVS, including DMIM model calls.

3.3.1 Interpreting the Stand Average Table Data

This table contains dwarf mistletoe infection and mortality information displayed as averages over the entire stand, all species combined.

The DMIM stand average summary table presents mistletoe-induced infection, intensification, and mortality statistics on a trees-per-acre (TPA) basis over the entire stand, all species combined. This table is produced automatically in the FVS main output file when mistletoe is present in the stand; DMIM keywords are not required. When the DBS extension is present, it is also possible to place this table in a database table called FVS_DM_Stnd_Sum by using the DBS MISRPTS keyword (see Exhibit 3.12 and Crookston and Gammel (2003) for additional details). The table lists information by cycle for each of the following areas:

- stand age;
- TPA, basal area, and volume totals at the beginning of the cycle;
- TPA, basal area, and volume of total trees with mistletoe infection;
- TPA, basal area, and volume of total trees killed by mistletoe;
- percentages of TPA and volume of infected trees;
- percentages of TPA and volume of mortality trees;
- an average dwarf mistletoe rating (DMR) for the entire stand; and
- an average dwarf mistletoe rating (DMI) of infected-only trees in the stand.

Mistletoe infection and mortality totals, percentages, and average DMR for the stand for total and infected-only trees are all calculated at the middle of a FVS cycle, whether it is the default 10-year cycle or any other length cycle. This happens after diameter growth has been modified due to mistletoe, after mistletoe has spread and intensified through the stand, and after mortality due to mistletoe infection has been calculated. Another thing to note is that stand total values, mistletoe infection values, percentages of infected trees, stand average DMR, and infected-only trees DMR all include mistletoe mortality statistics for that cycle also.

Exhibit 3.16 is an example of the stand average summary table.

```
                        DWARF MISTLETOE INFECTION AND MORTALITY STATISTICS SUMMARY TABLE
                                        (STAND COMPOSITE; PER ACRE)
--------------------------------------------------------------------------------------------------------------

Stand ID: 002047.0015b                 Management Code: NONE   Revision code: 991201

DMRs and DMIs calculated for trees with DBH >= 0.0
MEAN DMR = Average dwarf mistletoe rating for all trees in the stand.             * --WARNING-- Calculation may
MEAN DMI = Average dwarf mistletoe rating for infected-only trees in the stand.        include nonhost species.

               START OF CYCLE       DM INFECTION        DM MORTALITY
             ------------------  ------------------  ------------------                                *
             TREES   BA    VOL   TREES   BA    VOL   TREES   BA    VOL    %TPA  %VOL   %TPA  %VOL   MEAN  MEAN
YEAR   AGE   /ACRE  SQFT  CU FT  /ACRE  SQFT  CU FT  /ACRE  SQFT  CU FT    INF   INF   MORT  MORT    DMR   DMI
----   ---   -----  ----  -----  -----  ----  -----  -----  ----  -----   ----  ----   ----  ----   ----  ----
2000    74    3649   188   4201    197    42    931     10     2     51      5    22      0     1    0.1   2.6
2010    84    2537   125   3469     38    26    734      2     1     39      2    21      0     1    0.0   3.0
2020    94    3618    23    767      1     9    304      0     0     11      0    40      0     1    0.0   2.0
2030   104    3571   135   1837      1    23    311      0     1     12      0    17      0     1    0.0   2.0
2040   114    2635   236   4319      1    17    315      0     1     12      0     7      0     0    0.0   2.0
2050   124    5261    22    781      1     8    293      0     0     11      0    38      0     1    0.0   2.0
2060   134    4124   150   1925      1    23    291      0     1     11      0    15      0     1    0.0   2.0
2070   144    2650   238   4455      1    15    289      0     1     11      0     6      0     0    0.0   2.0
2080   154    5290    19    684      1     7    265      0     0     10      0    39      0     1    0.0   2.0
2090   164    4059   154   1916      1    21    261      0     1     10      0    14      0     1    0.0   2.0
2100   174    8109    19    567      1     8    237      0     0      9      0    42      0     2    0.0   2.0
```

Exhibit 3.16 An example of the stand average summary table.

3.3.2 Interpreting the Species-Specific Table Data

This table contains dwarf mistletoe infection and mortality information displayed by individual species in the stand, from the most infected to the least infected species.

The DMIM species-specific summary table presents mistletoe-induced infection, intensification, and mortality statistics for the four species with the highest percentage of dwarf mistletoe-infected trees per acre. The four most-infected species are ordered from the most- to least infected at the first cycle, and remain in this order through the run. This table is produced automatically in the FVS main output file when mistletoe is present in the stand; DMIM keywords are not required. When the DBS extension is present, it is also possible to place this table in a database table called FVS_DM_Spp_Sum by using the DBS MISRPTS keyword (see Exhibit 3.12 and Crookston and Gammel (2003) for additional details). The table lists information by cycle for each of the four species, for each of the following areas:

- trees per acre (TPA) with mistletoe infection;
- TPA killed by mistletoe infection;
- TPA percentages of mistletoe-infected trees;
- TPA percentages of mistletoe mortality trees;
- an average dwarf mistletoe rating of all trees of that species;
- an average dwarf mistletoe rating of infected-only trees of that species; and
- TPA percent representation of each species in the entire stand.

Mistletoe infection and mortality totals, percentages, and average DMR for each of the species for total and infected-only trees are all calculated at the middle of a FVS cycle, whether it is the default 10-year cycle or any other length cycle. This happens ***after*** diameter growth has been modified due to mistletoe, ***after*** mistletoe has spread and intensified through the stand, and ***after*** mortality figures due to mistletoe infection have been calculated. Another thing to note is that mistletoe infection values, percentages of infected trees, species average DMR, and species-infected-only DMR all include mistletoe mortality statistics for that cycle also.

Exhibit 3.17 is an example of the species-specific summary table.

DWARF MISTLETOE INFECTION AND MORTALITY STATISTICS SUMMARY TABLE
(BY SPECIES; TOP 4 MOST INFECTED SPECIES)

Stand ID: 002047.0015b   Management Code: NONE   Revision code: 991201

DMRs and DMIs calculated for trees with DBH >= 0.0
MEAN DMR = Average dwarf mistletoe rating for all trees of that species.
MEAN DMI = Average dwarf mistletoe rating for infected-only trees of that species.

YEAR	MEAN DMR				MEAN DMI				TPA INFECTED WITH DM				TPA MORTALITY FROM DM				% TPA INFECTED				% TPA MORTALITY				COMPOSITION OF STAND (%TPA)			
	LP	**	**	**	LP	**	**	**	LP	**	**	**	LP	**	**	**	LP	**	**	**	LP	**	**	**	LP	**	**	**
2000	0.3	0.0	0.0	0.0	2.6	0.0	0.0	0.0	197	0	0	0	10	0	0	0	13	0	0	0	1	0	0	0	43	0	0	0
2010	1.2	0.0	0.0	0.0	3.0	0.0	0.0	0.0	38	0	0	0	2	0	0	0	39	0	0	0	2	0	0	0	4	0	0	0
2020	0.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	28	0	0	0	1	0	0	0	0	0	0	0
2030	0.5	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	27	0	0	0	1	0	0	0	0	0	0	0
2040	0.5	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	27	0	0	0	1	0	0	0	0	0	0	0
2050	0.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	28	0	0	0	1	0	0	0	0	0	0	0
2060	0.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	31	0	0	0	1	0	0	0	0	0	0	0
2070	0.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	30	0	0	0	1	0	0	0	0	0	0	0
2080	0.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	31	0	0	0	1	0	0	0	0	0	0	0
2090	0.7	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	34	0	0	0	1	0	0	0	0	0	0	0
2100	0.7	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1	0	0	0	0	0	0	0	36	0	0	0	1	0	0	0	0	0	0	0

Exhibit 3.17 An example of the species-specific summary table.

3.3.3 Interpreting the Diameter Class Table Data

This table contains dwarf mistletoe infection and mortality information for each diameter class in the stand, by two-inch diameter classes ranging from 2 to 20 inches.

The DMIM diameter class table presents mistletoe-induced infection, intensification, and mortality statistics grouped by 2-inch DBH classes from 0 to 20+ inches, all species combined. This table is printed to the main FVS output file only when requested using the MISTPRT keyword. When the DBS extension is present, it is also possible to place this table in a database table called FVS_DM_Sz_Sum by using the DBS MISRPTS keyword (see Exhibit 3.12 and Crookston and Gammel (2003) for additional details). The table lists information by cycle for each of the 2-inch DBH classes from 0 to 20 inches, for each of the following areas:

- trees per acre (TPA) total;
- TPA with mistletoe infection;
- TPA killed by mistletoe infection;
- an average dwarf mistletoe rating (DMR) of all trees in that DBH class; and
- an average dwarf mistletoe rating (DMI) of infected-only trees of that DBH class.

Mistletoe infection totals, mortality totals, and average DMR for the DBH classes for total and infected-only trees are all calculated at the middle of a FVS cycle, whether it is the default 10-year cycle or any other length cycle. This happens ***after*** diameter growth has been modified due to mistletoe, ***after*** mistletoe has spread and intensified through the stand, and ***after*** mortality figures due to mistletoe infection have been calculated. Another thing to note is that the TPA total values, TPA with mistletoe infection values, average DMR for the total DBH class, and average DMR for infected-only trees of that DBH class all include mistletoe mortality statistics for that cycle also.

Exhibit 3.18 is an example of the diameter class summary table.

```
                        DWARF MISTLETOE INFECTION AND MORTALITY STATISTICS SUMMARY TABLE
                                          (BY 2 INCH DIAMETER CLASSES)
------------------------------------------------------------------------------------------------------------------------

Stand ID: 002047.0015b                 Management Code: NONE   Revision code: 991201

DMRs and DMIs calculated for trees with DBH >= 0.0
MEAN DMR = Average dwarf mistletoe rating for all trees of that diameter class.
MEAN DMI = Average dwarf mistletoe rating for infected-only trees of that diameter class.

YEAR                                                   2 INCH DIAMETER CLASSES
----         ---------------------------------------------------------------------------------------------------------
              0-2.9"     3-4.9"     5-6.9"     7-8.9"     9-10.9"   11-12.9"   13-14.9"   15-16.9"   17-18.9"    19  +"
             --------   --------   --------   --------   --------   --------   --------   --------   --------   --------
2000
       TPA    2950.0      419.7       33.7      169.8       58.9        0.0        7.4        0.0        0.0        9.7
       INF      50.0      100.0        0.0       27.5       17.0        0.0        0.0        0.0        0.0        2.8
       MRT       2.3        4.5        0.0        2.0        1.1        0.0        0.0        0.0        0.0        0.1
       DMR       0.0        0.5        0.0        0.6        1.4        0.0        0.0        0.0        0.0        0.9
       DMI       2.0        2.0        0.0        4.0        5.0        0.0        0.0        0.0        0.0        3.2
2010
       TPA    2320.9       55.2       31.3       28.1       68.3       19.2        1.9        3.9        0.0        8.1
       INF       0.0       15.4        5.1        8.7        6.4        0.0        0.0        0.0        0.0        2.4
       MRT       0.0        0.7        0.2        0.6        0.4        0.0        0.0        0.0        0.0        0.1
       DMR       0.0        0.6        0.3        1.2        0.5        0.0        0.0        0.0        0.0        0.9
       DMI       0.0        2.0        2.0        4.0        5.0        0.0        0.0        0.0        0.0        3.2
2020
       TPA    3614.2        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        3.5
       INF       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        1.0
       MRT       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
       DMR       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.6
       DMI       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        2.0
2030
       TPA    3523.9       43.4        0.0        0.0        0.0        0.0        0.0        0.0        0.0        3.4
       INF       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.9
       MRT       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
       DMR       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.5
       DMI       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        2.0
2040
       TPA       0.0     2622.2        9.5        0.0        0.0        0.0        0.0        0.0        0.0        3.3
       INF       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.9
       MRT       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
       DMR       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.5
       DMI       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        2.0
```

Exhibit 3.18 An example of the diameter class summary table.

3.3.4 *Interpreting the Species/DBH Class Table Data*

This table contains dwarf mistletoe infection and mortality information for each diameter class (from 2 to 40 inches) by species and by cycle.

The DMIM species/DBH table presents mistletoe-induced infection, intensification, and mortality statistics broken down first by cycle, then by species, and finally by 2-inch DBH classes from 0 to 40+ inches. This table is printed to the main FVS output file only when requested using the MISTABLE keyword. This table is not available as an output to the DBS extension. It can be requested for any one or all infected species and for any one or all cycles. Each table then lists information for 20 different 2-inch DBH classes from 0 to 40+ inches. The table lists information by cycle, by species, for each 2-inch DBH class from 0 to 40+ inches for each of the following areas:

- trees per acre (TPA) total;
- TPA with mistletoe infection;
- TPA without mistletoe infection (DMR=0);
- TPA per acre with DMR 1 or 2;
- TPA per acre with DMR 3 or 4;
- TPA per acre with DMR 5 or 6;
- TPA killed by mistletoe infection;
- an average dwarf mistletoe rating (DMR) for all trees of that species/DBH class; and
- an average dwarf mistletoe rating (DMI) of infected-only trees of that species/DBH class.

Mistletoe infection, mortality, and DMR-specific totals, and average DMR for each class for total and infected-only trees are all calculated at the middle of a FVS cycle, whether it is the default 10-year cycle or any other length cycle. This happens ***after*** diameter growth has been modified due to mistletoe, ***after*** mistletoe has spread and intensified through the stand, and ***after*** mortality figures due to mistletoe infection have been calculated. Another thing to note is that TPA totals, TPA with mistletoe infection, TPA broken down by DMR, and average DMR for each class (total and infected-only trees) all include mistletoe mortality statistics for that cycle also.

Exhibit 3.19 is an example of the species/DBH class detailed table.

DWARF MISTLETOE INFECTION AND MORTALITY STATISTICS DETAIL TABLE
(BY SPECIES, BY 2 INCH DIAMETER CLASS, BY CYCLE)

Stand ID: 002047.0015b Management Code: NONE Revision code: 991201

DMRs and DMIs calculated for trees with DBH >= 0.0
MEAN DMR = Average DM rating for all trees of that species/DBH class.
MEAN DMI = Average DM rating for infected-only trees of that species/DBH class.

Year: 2000
Species: LP

DBH CLASS	TREES/ACRE TOTAL	TREES/ACRE INFECTED	TREES/ACRE UNINFECTED	TREES/ACRE DMR 1-2	TREES/ACRE DMR 3-4	TREES/ACRE DMR 5-6	TREES/ACRE MORTALITY	MEAN DMR	MEAN DMI
0- 2.9"	1200.0	50.0	1150.0	50.0	0.0	0.0	2.3	0.1	2.0
3- 4.9"	300.0	100.0	200.0	100.0	0.0	0.0	4.5	0.7	2.0
5- 6.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7- 8.9"	27.5	27.5	0.0	0.0	27.5	0.0	2.0	4.0	4.0
9-10.9"	31.9	17.0	15.0	0.0	0.0	17.0	1.1	2.7	5.0
11-12.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13-14.9"	7.4	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0
15-16.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-18.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19-20.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21-22.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23-24.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25-26.9"	2.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
27-28.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29-30.9"	5.1	1.7	3.4	0.0	1.7	0.0	0.1	1.3	4.0
31-32.9"	1.5	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
33-34.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35-36.9"	1.1	1.1	0.0	1.1	0.0	0.0	0.0	2.0	2.0
37-38.9"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39+ "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SUM/AVG	1576.5	197.3	1379.2	151.1	29.2	17.0	10.1	0.3	2.6

Exhibit 3.19 An example of the species/DBH class detailed table.

Appendices

Appendix A.
Tree Species Abbreviations, Common Names, and Scientific Names

The following is a list of the tree species abbreviations used in this document, and the common and scientific names to which these abbreviations refer.

Abbreviation	Common Name	Scientific Name
AF	subalpine fir	Abies lasiocarpa
AS	aspen	Populus tremuloides
BC	cherry	Prunus spp.
BM	bigleaf maple	Acer macrophyllum
BO	California black oak	Quercus kelloggi
BS	blue spruce	Picea pungens
C	western red cedar	Thuja plicata
CB	corkbark fir	Abies lasiocarpa var. arizonica
CO	plains cottonwood	Populus trichocarpa
CW	black cottonwood	Populus deltoides var. occidentalis
DF	Douglas-fir	Pseudotsuga menziesii
DG	western dogwood	Cornus sericea var. occidentalis
ES	Engelmann spruce	Picea engelmannii
GC	giant chinkapin	Casanopsis chrsophylla
GF	grand fir	Abies grandis
GS	giant sequoia	Sequoiadentron gigantum
HD	hardwood	--
HT	hawthorn	Crataegus douglasii
IC	incense cedar	Libocedrus decurrens
J	juniper	Juniperus spp.
JP	Jeffrey pine	Pinus jeffreyi
KP	knobcone pine	Pinus attenuata
L	western larch	Larix occidentalis
LL	subalpine larch	Larix lyallii
LM	limber pine	Pinus flexilis
LP	lodgepole pine	Pinus contorta

Abbreviation	Common Name	Scientific Name
M	Pacific madrone	Arbutus menziesii
MH	mountain hemlock	Tsuga mertensiana
NF	noble fir	Abies procera
OA	oak	Quercus
OC	other conifer	--
OH	other hardwood	--
OS	other softwood	--
P	pinyon	Pinus edulis
PB	paper birch	Betula papyrifera
PJ	pinyon-juniper	--
PP	ponderosa pine	Pinus ponderosa
PY	pacific yew	Taxus brevifolia
RA	red alder	Alnus rubra
RC	western red cedar	Thuja plicata
RF	red fir	Abies magnifica
RW	coastal redwood	Sequoia sempervirens
SF	Pacific silver fir	Abies amabilis
SP	sugar pine	Pinus lambertiana
S	Engelmann spruce	Picea engelmannii
SS	Sitka spruce	Picea sitchensis
TO	Tanoak	Lithocarpus densiflorus
WA	white alder	Alnus rhombifolia
WA	white ash	Fraxinus americana
WB	whitebark pine	Pinus albicaulis
WF	white fir	Abies concolor
WH	western hemlock	Tsuga heterophylla
WI	willow	Salix spp.
WL	western larch	Larix occidentalis
WO	white oak	Quercus alba
WP	western white pine	Pinus monticola
WS	white spruce	Picea glauca
YC	Alaska yellow cedar	Chamaecyparis nootkatensis

Appendix B.
Abbreviations and Glossary

The following are phrases, words, and acronyms used in this document.

Abbreviation/Term	Explanation
active infection	mistletoe plant that produces seed
BA	basal area (usually square feet/acre)
binomial	a discrete probability distribution in which there are fewer cases of larger and smaller samples than expected from a random distribution; sample variance smaller than sample mean
CL	FVS (Prognosis) cycle length (years)
crownthird	the vertical division of a tree's canopy into three equal-height divisions
DBH	diameter at breast height (usually inches)
DM	dwarf mistletoe
DMI	dwarf mistletoe rating , infected-only trees (0-6)
DMR	dwarf mistletoe rating (0-6 in Hawksworth's scale)
EXP	exponential function; exp(x) is also written e^x
DMIM	Dwarf Mistletoe Impact Model
INF	dwarf mistletoe infection (units vary)
MRT	dwarf mistletoe-induced mortality (units vary)
negative binomial	A discrete probability distribution in which there are more cases of larger and smaller samples than expected from a random distribution; sample variance larger than sample mean
poisson	a discrete probability distribution often referred to as "random"; sample variance equals sample mean
TPA	trees per acre
VOL	volume (units vary)

Appendix C.
Species Infested with Dwarf Mistletoe

The following species in each region can serve as a host to dwarf mistletoe.

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
S.E. Alaska (AK)	Pacific silver fir Western hemlock Lodgepole pine Subalpine fir	White spruce Western redcedar Mountain hemlock Yellow cedar Sitka spruce Red alder Black cottonwood Other hardwood Other softwood
Blue Mountains (BM)	Western larch Douglas-fir Lodgepole pine Ponderosa pine Whitebark pine Limber pine	White pine Grand fir Mountain hemlock Western juniper Engelmann spruce Subalpine fir Pacific yew Alaska yellow cedar Quaking aspen Black cottonwood Other softwoods Other hardwoods
Kootenai / Kaniksu / Tally Lake (KT)	Western larch Douglas-fir Lodgepole pine Ponderosa pine	Western hemlock Western redcedar Engelmann spruce Western white pine Grand fir Subalpine fir Other species
Klamath Mountains – Northern California (NC)	Sugar pine Douglas-fir White fir Red fir Ponderosa pine	Other conifers Madrone Incense-cedar California black oak Tanoak Other hardwood
Northern Idaho / Inland Empire (11 species) (NI)	Western larch Douglas-fir Lodgepole pine Ponderosa pine	Western hemlock Western redcedar Engelmann Spruce Western white pine Grand fir Subalpine fir Other species

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Inland California/Southern Cascades (CA)	White pine	Port-Orford-cedar
	Red fir	Incense-cedar
	Shasta red fir	Western redcedar
	Douglas-fir	Coulter pine
	Western hemlock	Monterey pine
	Mountain hemlock	Gray pine
	Whitebark pine	Western juniper
	Knobcone pine	Brewer spruce
	Lodgepole pine	Giant sequoia
	Limber pine	Pacific yew
	Jeffrey pine	Other softwoods
	Sugar pine	Coast live oak
	White pine	Canyon live oak
	Ponderosa pine	Blue oak
		Engelmann oak
		Oregon white oak
		California black oak
		Valley white oak
		Interior live oak
		Bigleaf maple
		California buckeye
		Red alder
		Pacific madrone
		Golden chinkapin
		Pacific dogwood
		Oregon ash
		Walnut
		Tanoak
		Califonia sycamore
		Quaking aspen
		Black cottonwood
		Willow
		California nutmeg
		California laurel
		Other hardwoods
Central Idaho (CI)	western white pine	western hemlock
	western larch	western redcedar
	Douglas-fir	Engelmann spruce
	grand fir	Pacific yew
	lodgepole pine	quaking aspen
	subalpine fir	western juniper
	ponderosa pine	curlleaf mountain-mahogany
	whitebark pine	black cottonwood
	limber pine	other softwoods
		other hardwoods

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Central Rockies (CR)	Subalpine fir	Western redcedar
Model types:	Corkbark fir	Utah juniper
- S.W. Mixed Conifer	Douglas-fir	White spruce
- S.W. Ponderosa Pine	Grand fir	Quaking aspen
- Black Hills *	White fir	Narrowleaf cottonwood
- Spruce-Fir	Mountain hemlock	Plains cottonwood
- Lodgepole Pine	Western larch	Gambel oak
	Bristlecone pine	Arizona white oak
	Limber pine	Emory oak
	Lodgepole pine	Bur oak
	Pinyon pine	Silverleaf oak
	Ponderosa pine	Paper birch
	Whitebark pine	Alligator juniper
	Southwestern white pine	Rocky Mountain juniper
	Blue spruce	Oneseed juniper
	Engelmann spruce	Eastern redcedar
	Singleleaf pinyon	Other softwoods
	Border pinyon	Other hardwoods
	Arizona pinyon pine	
	Chihuahua pine	
East Cascades (EC)	Western white pine	Western redcedar
	Western larch	Engelmann spruce
	Douglas-fir	Pacific yew
	Pacific silver fir	Whitebark pine
	Grand fir	Subalpine larch
	Lodgepole pine	Alaska cedar
	Subalpine fir	Western juniper
	Ponderosa pine	Bigleaf maple
	Western hemlock	Vine maple
	Mountain hemlock	Red alder
	Noble fir	Paper birch
	White fir	Golden chinkapin
		Pacific dogwood
		Quaking aspen
		Black cottonwood
		Oregon white oak
		Cherry and plum species
		Willow species
		Other softwoods
		Other hardwoods

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Eastern Montana (EM)	Whitebark pine Douglas-fir Limber pine Lodgepole pine	Western larch Subalpine larch Rocky Mountain juniper Engelmann spruce Subalpine fir Ponderosa pine Green ash Quaking aspen Black cottonwood Balsam poplar Plains cottonwood Narrowleaf cottonwood Paper birch Other softwoods Other hardwoods
Northern Idaho / Inland Empire (23 species) (IE)	Western larch Douglas-fir Lodgepole pine Ponderosa pine Whitebark pine Limber pine	Western white pine Grand fir Western hemlock Western redcedar Engelmann spruce Subalpine fir Mountain hemlock Subalpine larch Pinyon pine Western juniper Pacific yew Quaking aspen Plains cottonwood Mountain maple Paper birch Other hardwoods Other softwoods

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Pacific Northwest Coast (PN)	Subalpine fir	Pacific silver fir
	California red fir	White fir
	Lodgepole pine	Grand fir
	Douglas-fir	Sitka spruce
	Western hemlock	Noble fir
	Mountain hemlock	Yellow cedar/Western Larch
		Incense-cedar
		Engelmann spruce
		Jeffrey pine
		Sugar pine
		Western white pine
		Ponderosa pine
		Coast redwood
		Western redcedar
		Bigleaf maple
		Red alder
		White alder/Pacific madrone
		Western paper birch
		Giant chinkapin/Tanoak
		Quaking aspen
		Black cottonwood
		Oregon white oak/California black
		Juniper
		Subalpine larch
		Whitebark pine
		Knobcone pine
		Pacific yew
		Pacific dogwood
		Hawthorn
		Bitter cherry
		Willow
		Other species
S. Oregon N.E. California – SORNEC (SO)	white pine	incense-cedar
	sugar pine	Engelmann spruce
	Douglas-fir	juniper
	white fir	Pacific yew
	mountain hemlock	white alder
	lodgepole pine	red alder
	shasta red fir	bigleaf maple
	ponderosa pine	quaking aspen
	grand fir	black cottonwood
	subalpine fir	bitter cherry
	Pacific silver fir	Oregon white oak
	noble fir	willow
	whitebark pine	giant chinkapin
	western larch	curl-leaf mountain mahogany
	western redcedar	birchleaf mountain mahogany
	western hemlock	

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Utah (UT)	whitebark pine	quaking aspen
	limber pine	western juniper
	Douglas-fir	Gambel oak
	white fir	Rocky Mountain juniper
	blue spruce	Utah juniper
	lodgepole pine	narrowleaf cottonwood
	Engelmann spruce	Fremont cottonwood
	subalpine fir	curl-leaf mountain mahogany
	ponderosa pine	bigtooth maple
	common pinyon	boxelder
	singleleaf pinyon	other softwoods
	Great Basin bristlecone pine	other hardwoods
Tetons(TT)	Whitebark pine	Quaking aspen
	Limber pine	Engelmann spruce
	Douglas-fir	Utah juniper
	Singleleaf pinyon	Rocky Mountain juniper
	Blue spruce	Bigtooth maple
	Lodgepole pine	Rocky Mountain maple
	Subalpine fir	Narrowleaf cottonwood
	Ponderosa pine	Curl-leaf mountain mahogany
		Other softwoods
		Other hardwoods
West Cascades (WC)	Pacific silver fir	Yellow cedar
	White fir	Incense-cedar
	Grand fir	Engelmann spruce
	Subalpine fir	Jeffrey pine
	California red fir	Sugar pine
	Noble fir	Coast redwood
	Lodgepole pine	Western redcedar
	Western white pine	Bigleaf maple
	Ponderosa pine	Red alder
	Douglas-fir	White alder / Pacific madrone
	Western hemlock	Paper birch
	Mountain hemlock	Giant chinkapin / tanoak
	Knobcone pine	Quaking aspen
		Black cottonwood
		OR white oak / CA black oak
		Juniper
		Subalpine larch
		Whitebark pine
		Pacific yew
		Pacific dogwood
		Hawthorn
		Bitter cherry
		Willow
		Other species

FVS Variant	Species affected by dwarf mistletoe	Species not affected by dwarf mistletoe
Western Sierra Nevada – WESSIN (WS)	sugar pine	giant sequoia
	Douglas-fir	incense-cedar
	white fir	redwood
	Jeffrey pine	western juniper
	California red fir	Utah juniper
	ponderosa pine	California juniper
	lodgepole pine	California live oak
	whitebark pine	canyon live oak
	western white pine	blue oak
	singleleaf pinyon	California black oak
	Pacific silver fir	California white oak / valley oak
	knobcone pine	interior live oak
	foxtail pine	tanoak
	Coulter pine	giant chinkapin
	limber pine	quaking aspen
	Monterey pine	California-laurel
	Gray or California foothill pine	Pacific madrone
	Washoe pine	Pacific dogwood
	Great Basin bristlecone pine	bigleaf maple
	bigcone Douglas-fir	curlleaf mountain-mahogany
	mountain hemlock	other softwoods
		other hardwoods

* Although dwarf mistletoe is not present in the Black Hills, tree species being eligible as host is not a concern because dwarf mistletoe infections will not sporadically appear in any simulation. Dwarf mistletoe can only exist in a simulation in two ways: 1) the presence of dwarf mistletoe damage codes in the input data set or 2) manually introduced to the simulation using Dwarf Mistletoe Model keywords.

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Region 2:

Frank Hawksworth (DM information)
Michael Marsden (DM information)
Ralph Johnson, Gary Dixon (existing FVS model)
Matt Thompson, Lance David (existing FVS model)
Brian Geils (southwest Douglas-fir mortality data)

Region 5:

Dennis Hart (true fir mortality and diameter growth data)

Region 6:

Jerry Beatty (mortality and diameter growth information)
Catherine Parks (same)
Ellen Michaels Goheen (same)
Don Goheen (same)
Kathy Sheehan (same)
Helen Maffei (same)
Tommy Gregg (same)
Paul Hessburg (same)
L.F. Roth (Pringle Falls data)

Region 10:

Paul Hennon